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ENCYCLOPÆDIA OF CHEMISTRY.

ENCYCLOPÆDIA

OF

CHEMISTRY

THEORETICAL, PRACTICAL, AND ANALYTICAL

AS APPLIED TO

THE ARTS AND MANUFACTURES.

BY WRITERS OF EMINENCE.

ILLUSTRATED WITH NUMEROUS WOOD-CUTS AND STEEL-PLATE ENGRAVINGS.

VOL. I.

ACETIC ACID——GAS.

PHILADELPHIA:
J. B. LIPPINCOTT & CO.
1877.

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PREFATORY NOTICE.

Even in the present age, when Progress is emphatically the watchword of all arts and sciences alike, few have advanced with greater or more rapid strides than Chemistry, both in the departments of theory and practice.

It is now upwards of twenty years since a work on "Chemistry as applied to the Arts and Manufactures," edited by the late Dr. Muspratt, was projected, which represented the state of knowledge of that day on this most important subject. The reception which that work met with, and the great circulation it at once attained, were convincing proofs that it supplied a want which up to that time had been keenly felt; and even to a very recent period the demand for it has been such as to show that it occupied a place in the first rank of our industrial literature.

Twenty years, however, have made stupendous changes in our chemical industries. Not a few which were not even dreamed of at that time have since sprung into existence, and now occupy positions of the greatest importance, while of the rest there are few that have not been greatly changed, or even wholly remodelled, by recent discoveries or improved practice. The "notation" itself has not escaped, having been replaced of late years by a more modern system.

These facts convinced the Publishers of the existence of a want for a work which should embrace alike the latest scientific knowledge and the most recent practical inventions and appliances in this great department of industry; and to meet this want the present publication was undertaken. Its plan, formed on the model of its well-known predecessor, includes such novel features as are likely to make it even more convenient and valuable than was that work in its day.

It being manifest that the infinite variety of subjects now embraced in such a work could be adequately treated by no one writer, however learned or painstaking, the Publishers in carrying forward their enterprise have availed themselves of the assistance of the leading chemists of the present day, as well as of writers who are practically acquainted with all the details of our great manufactures; while no expense has been spared to add to the clearness and usefulness of the articles by means of copious illustrations. This department of the work will be found to comprise, besides very numerous Woodcuts in the text, a series of highly-finished Plate Engravings of the most important or elaborate manufacturing plant in use at the present time,—a feature, it is hoped, which will add greatly to its value and interest.

It will be seen that the alphabetical arrangement, which has been found best adapted to the requirements of the case, has been adopted, and this is supplemented by a copious index, by which reference can be made to many subjects of minor importance which are treated in the course of the larger articles. The aim has been throughout to make each article a full and reliable treatise, and to avoid the error, so common in dictionary articles, of making a large proportion mere passing notices, than which nothing could be more unsatisfactory and disappointing to the practical inquirer. That by careful attention to these principles the present work has been made worthy alike of the reputation of its predecessor, and of the large and ever-growing branch of industry it is its aim to represent, is the hope of

THE PUBLISHERS.

PLATES.

VOL. I.

PAGE

ALCOHOL. PLATE I. SECTION OF WHISKY DISTILLERY 101

ANILINE. PLATE I. APPARATUS FOR THE FRACTIONAL DISTILLATION OF ANILINE OILS 214

ARSENIC. PLATE I. BRUNTON'S CALCINER 255

BEER. PLATE I. SECTION OF BREWERY 327

BENZOL. PLATE I. STILLS 345

CANDLE. PLATE I. COWLES' CANDLE MOULDING MACHINE . . . 449

CHLORINE. PLATE I. APPARATUS FOR THE MANUFACTURE OF CHLORINE BY WELDON'S PROCESS 481

CHLORINE. PLATE II. WELDON'S CHLORINE STILL 483

CHLORINE. PLATE III. DEACON'S DECOMPOSING TOWERS 487

COPPER. PLATE I. WET COPPER EXTRACTION. SPONGY IRON FURNACE. 568

DISINFECTANTS. PLATE I. DISINFECTING APPARATUS AT NEW BIRD STREET, LIVERPOOL 618

DYEING AND CALICO PRINTING. PLATE I. SECTIONAL ELEVATION OF TWELVE COLOUR MACHINE BY THOMAS GADD 675

DYEING AND CALICO PRINTING. PLATE II. FRONT ELEVATION OF EIGHT COLOUR MACHINE BY THOMAS GADD 676

DYEING AND CALICO PRINTING. PLATE III. ELEVATION OF TWENTY COLOUR MACHINE BY THOMAS GADD 678

DYEING AND CALICO PRINTING. PLATE IV. EIGHT COLOUR PRINTING MACHINE BY TULPIN FRERES. FRONT VIEW 680

DYEING AND CALICO PRINTING. PLATE V. EIGHT COLOUR PRINTING MACHINE BY TULPIN FRERES. SIDE VIEW 682

ELECTRO METALLURGY. PLATE I. GRAMME'S MACHINE 806

EXPLOSIVES. PLATE I. APPARATUS FOR PREPARING GUN COTTON . . 852

EXPLOSIVES. PLATE II. " " " " . . 854

FUEL. PLATE I. SIEMENS' GAS PRODUCER 973

FUEL. PLATE II. LONGITUDINAL SECTION OF SIEMENS' ROTARY FURNACE FOR THE DIRECT MANUFACTURE OF IRON AND STEEL . . 978

FUEL. PLATE III. SECTIONAL PLAN OF SIEMENS' ROTARY FURNACE FOR THE DIRECT MANUFACTURE OF IRON AND STEEL . . . 978

FUEL. PLATE IV. SIEMENS' STEEL MELTING FURNACE 980

GAS. PLATE I. APPARATUS FOR MANUFACTURE OF GAS 1001

GAS. PLATE II. LETHEBY'S PHOTOMETER 1033

CHEMISTRY,

THEORETICAL, PRACTICAL, AND ANALYTICAL,

AS APPLIED TO THE

ARTS AND MANUFACTURES.

ACETIC ACID.

ACETIC ACID.—*Acide Acétique*, French; *Essigsaure*, German; *Acidium Aceticum*, Latin; *Eisel*, Saxon; $C_2H_4O_2 = \left.\begin{matrix} C_2H_3O \\ H \end{matrix}\right\} O$, or $C_2H_3O_2H$. The hydrate or hydrated oxide of the as yet unisolated radicle acetyl (C_2H_3O). Acetic acid was formerly supposed to be a trioxide of the radicle C_2H_3 (old notation C_4H_3), the hydrated acid being a compound of this oxide ($C_4H_3O_3$) with water ($C_4H_3O_3,C_2H_3HO$). The assumption of the radicle acetyl enables the reactions of acetic acid to be represented very simply. Thus when potassium carbonate is added to dilute acetic acid, the basic atom of hydrogen is replaced by the metal, and potassium acetate is formed—$\left.\begin{matrix} C_2H_3 \\ K \end{matrix}\right\} O = KC_2H_3O_2$. In fact, acetic acid may be viewed as a molecule of water in which half the hydrogen is replaced by acetyl, and when the remainder of this hydrogen is replaced by a metal an acetate is produced.

Ordinary vinegar is dilute acetic acid, contaminated with various vegetable impurities. In this form it has been known from the earliest times. MOSES mentions it (Numbers vi. 3). HIPPOCRATES made use of it as a medicine; and though until very recently there was no definite knowledge as to the cause of its production and the mode of its formation, there can be no doubt that it was in very general use, and that most of its properties as regards its action on metals, &c., had been investigated at a very remote period.

The alchemists were acquainted with this acid in a concentrated state, and obtained it by distilling copper acetate (verdigris). Both GEBER and STAHL describe this process. The product of the further rectification of the liquid was termed *Radical vinegar*, *Spiritus Veneris*, *Venus' vinegar*, *Spiritus aeruginis*, &c.

Acetic acid was first obtained as a pure hydrate by LÖWITZ in 1793. Subsequently it was observed by Dr. J. DAVY that spongy platinum, in contact with the vapour of alcohol, became incandescent, and generated this acid. DÖBEREINER further studied the nature of the acid, and proved that the alcohol was oxidized at the expense of the atmospheric air, producing acetic acid and water, and that no carbonic acid was formed—thus pointing out the fallacy of the opinion held by the chemists of his time, that carbonic acid was one of the products of the acetous fermentation. Further, he showed that, for the complete oxidation of one atom of alcohol, four atoms of oxygen were required.

Glacial Acetic Acid.—Pure acetic acid ($C_2H_4O_2$) is at ordinary temperatures a crystalline solid. It is obtained by distilling finely powdered anhydrous metallic acetates with an equivalent quantity of concentrated sulphuric acid or potassium bisulphate. Thus with acetate of potassium and sulphuric acid:—

$$2KC_2H_3O_3 + H_2SO_4 = 2C_2H_4O_2 + K_2SO_4,$$

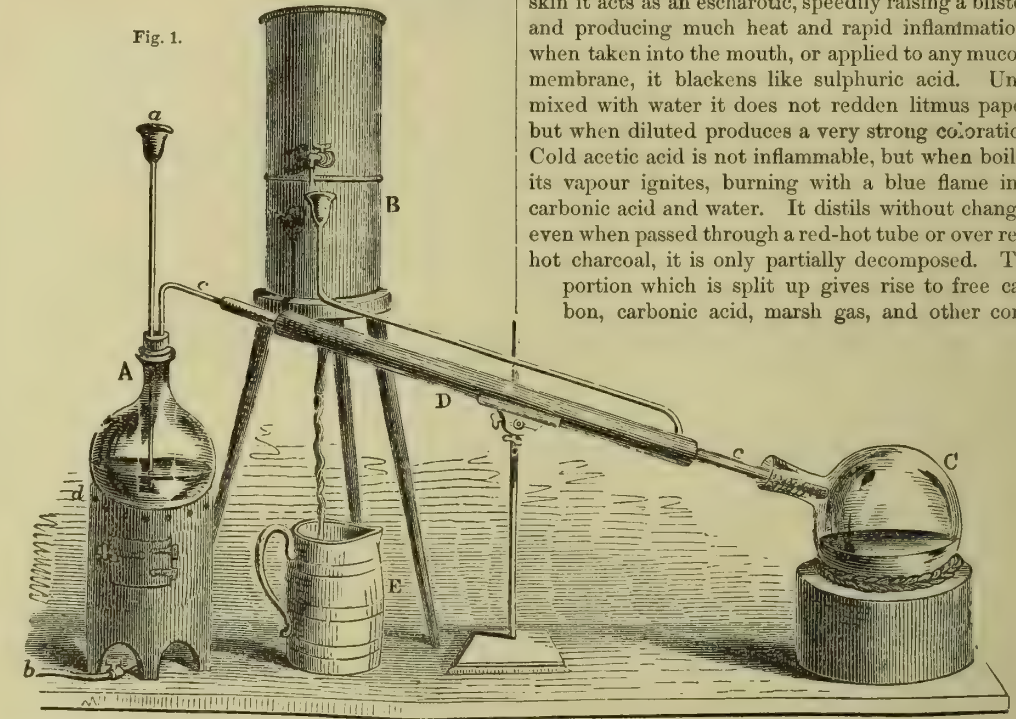
or with potassium bisulphate:—

$$KC_2H_3O_2 + KHSO_4 = C_2H_4O_2 + K_2SO_4.$$

The proportions are 98 of potassium acetate, 82 sodium acetate, 79 calcium acetate, or 163 lead acetate, to 49 of sulphuric acid (H_2SO_4), or 136 of potassium bisulphate ($KHSO_4$).

Fig. 1 is an apparatus well adapted for this purpose. A is a flask, closed by a cork, which receives two tubes; one of these is a funnel tube, *a*, through which the liquid bodies are introduced, and the other conducts the vapours to the condenser. This consists of an outer case, D, through which the tube, *c c*, connected with the bent tube from the flask, A, passes. The condenser is cooled by keeping a stream of water running constantly from the reservoir, B; C is a flask to receive the condensed vapours; *d*, the gas lamp which heats the liquid in A; *b* the gas pipe, and E the vessel into which the heated water flows from the condenser.

Fig. 1.



The odour of pure acetic acid is peculiarly suffocating, but when mixed with air it is very agreeable. It is a powerful restorative when applied to the nostrils in impending fainting. It is nearly as acrimonious as sulphuric acid; when dropped on the skin it acts as an escharotic, speedily raising a blister, and producing much heat and rapid inflammation; when taken into the mouth, or applied to any mucous membrane, it blackens like sulphuric acid. Until mixed with water it does not redden litmus paper, but when diluted produces a very strong coloration. Cold acetic acid is not inflammable, but when boiled its vapour ignites, burning with a blue flame into carbonic acid and water. It distils without change; even when passed through a red-hot tube or over red-hot charcoal, it is only partially decomposed. The portion which is split up gives rise to free carbon, carbonic acid, marsh gas, and other combustible gases, acetone, naphthaline, hydrate of phenyl, and benzol.

The specific gravity of acetic acid is 1·0635 at 15° C. (Mohr). It boils at 117° C. to 119° C., solidifies at 15° C., and melts at 16° C. On first addition of water heat is evolved, and a contraction of volume ensues until (20 to 22 per cent. of water having been added) a hydrate is formed, having the composition $C_2H_4O_2,H_2O$. This acid has the sp. gr. 1·0748, and boils at 104° C. On adding more water the density of the liquid again diminishes. Hence in determining the strength of acetic acid, the density is no criterion of the amount of acetic acid present.

The following table, drawn up by Mohr, shows that the specific gravity test answers very well, when it is required to determine the amount of anhydrous acid in dilute solutions; but when the acid increases in strength it is very fallacious:—

Per Cent.	Sp. Gr.	Per Cent.	Sp. Gr.	Per Cent.	Sp. Gr.	Per Cent.	Sp. Gr.	Per Cent.	Sp. Gr.
100	1·0635	80	1·0735	60	1·067	40	1·051	20	1·027
99	1·0655	79	1·0735	59	1·066	39	1·050	19	1·026
98	1·0670	78	1·0732	58	1·066	38	1·049	18	1·025
97	1·0680	77	1·0732	57	1·065	37	1·048	17	1·024
96	1·0690	76	1·0730	56	1·064	36	1·047	16	1·023
95	1·0700	75	1·0720	55	1·064	35	1·046	15	1·022
94	1·0706	74	1·0720	54	1·063	34	1·045	14	1·020
93	1·0708	73	1·0720	53	1·063	33	1·044	13	1·018
92	1·0716	72	1·0710	52	1·062	32	1·042	12	1·017
91	1·0721	71	1·0710	51	1·061	31	1·041	11	1·016
90	1·0730	70	1·0700	50	1·060	30	1·040	10	1·015
89	1·0730	69	1·0700	49	1·059	29	1·039	9	1·013
88	1·0730	68	1·0700	48	1·058	28	1·038	8	1·012
87	1·0730	67	1·0690	47	1·056	27	1·036	7	1·010
86	1·0730	66	1·0690	46	1·055	26	1·035	6	1·008
85	1·0730	65	1·0680	45	1·055	25	1·034	5	1·007
84	1·0730	64	1·0680	44	1·054	24	1·033	4	1·005
83	1·0730	63	1·0680	43	1·053	23	1·032	3	1·004
82	1·0730	62	1·0670	42	1·052	22	1·031	2	1·002
81	1·0732	61	1·0670	41	1·051	21	1·029	1	1·001

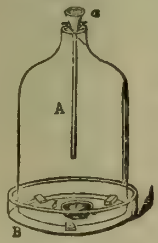
Acetic acid mixes with water in all proportions, and dissolves many essential oils, hydrocarbons, such as camphor, guiacum, and various resins, fibrinic of blood, gelatine, &c., and many other bodies which are insoluble in water. It is this peculiar power of solution which renders it when properly diluted and moderately used so valuable as a condiment. Free acetic acid is always in the stomach when in a healthy state, and the substitution for it of lactic acid is one of the most common accompaniments of indigestion. In cases of poisoning by alcohol, or with narcotic poisons, the power of acetic acid over the nervous system is very great. In the latter case care must be taken that the narcotic is first removed, as otherwise a powerful acetate would be formed; but after removal of the poison few substances more successfully combat the secondary symptoms.

In all its states the metal platinum possesses in a very high degree the property of condensing gases upon its surface. A clean plate of platinum condenses oxygen and hydrogen upon itself with such force, that if placed in a mixture of combining volumes of the two gases sufficient heat is disengaged to fire the remnant of the gases. When very finely divided platinum is used, the surface is so greatly extended that the phenomenon becomes still more striking from the rapidity with which the action is effected.

Spongy platinum is obtained by heating to redness the double chloride of platinum and ammonium. From its minute state of division it condenses within itself several hundred times its volume of oxygen; consequently, when the vapour of alcohol comes in contact with this body, a supply of oxygen in a concentrated state is presented to it, and the platinum, without losing any of its own inherent properties, effects chemical combination, the alcohol undergoing slow combustion, and being converted into acetic acid. In order that the reaction may continue, it is of course necessary to present fresh oxygen to the platinum, to replace that which is withdrawn. The two actions then go on side by side.

This can be illustrated by an apparatus similar to Fig. 2. A is a bell glass, through the mouth of which a long funnel, *a*, passes; the lower end of this funnel terminates in a fine point, so that the alcohol poured in may percolate very slowly. The vessel is placed upon supports, *b*, within a dish, B, in which is a saucer or small flat basin, containing the spongy platinum. The interstice between the bottom of the dish, B, and the bell, A, serves for the circulation of air in the jar. On pouring the alcohol through *a*, in the course of a short time the odour of acetic acid is perceived at the mouth, from the acetic acid vapours which are generated. These condense on the sides of the jar, and trickle to the bottom, where they collect in B. It is advantageous for the success of the experiment to have the alcohol heated to about 32° C. (90° Fahr.) when it is poured in. In Germany and other continental countries, where the duty on alcoholic liquors is not so high as in England, this method was formerly carried on as a commercial process, but it was found that so much of the alcohol was converted into aldehyde and lost by volatilization, that the manufacture was ultimately abandoned. The reaction is conceived to take place by two steps—

Fig. 2.

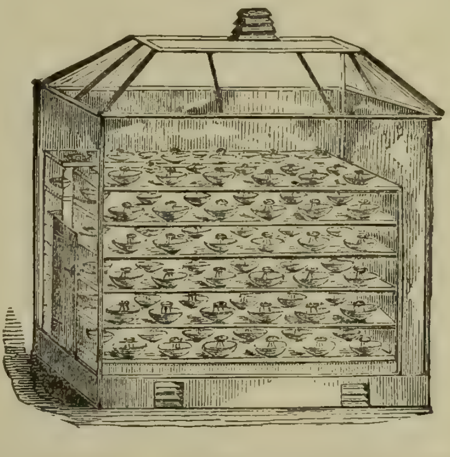


$$\underset{\text{Alcohol.}}{C_2H_6O} + O = \underset{\text{Aldehyde.}}{C_2H_4O} + \underset{\text{Water.}}{H_2O}$$

$$\text{and } \underset{\text{Aldehyde.}}{C_2H_4O} + O = \underset{\text{Acetic Acid.}}{C_2H_4O_2}.$$

On the large scale, a glass case, or one of wood, the roof of which is of glass to admit the heat of the sun, is constructed. In the interior of this case the shelves are arranged, twelve inches apart, on which a series of shallow glazed earthenware or porcelain dishes are placed; in each is a porcelain or stoneware tripod, bearing a watch-glass or small dish, containing the spongy metal. The alcohol is poured into these vessels, and no more than an inch and a half, or two inches, should intervene between the platinum in the watch-glasses and the surface of the alcohol in the flat dishes. If there be no arrangement to supply an influx of air in the place of that which becomes deoxidized, no more alcohol should be operated upon than the volume of air in the apparatus is capable of converting into acetic acid. This quantity may be inferred from the fact that 110 grains of alcohol require for their complete oxidation 1000 cubic inches of air, producing 120 grains of anhydrous acetic acid, and about 65 grains of water. If a draught be instituted, by which the vitiated or nitrogenous portion of the deoxidized air is withdrawn, and fresh quantities supplied by means of air-passages in the lower part of the chamber, the necessity of observing, with the accuracy previously mentioned, the amount of alcohol submitted to oxidation, is obviated. This arrangement is shown in Fig. 3. The temperature of the air in the case is raised to about 32° C. (90° Fahr.) by means of steam pipes or flues from a fire adjacent to the apparatus, similar to those in vineries in this country. Oxidation of the alcohol then commences, which is ascertained by the pungent odour of the acid. The

Fig. 3.



elevated temperature converts a portion of the alcohol into vapour, which, on coming into contact with the moistened platinum, undergoes incipient combustion, giving rise to the acid. These vapours condense, and are collected, for the most part, in the dishes; the remaining quantity trickles down into a receiver at the bottom of the case. In this manner the whole of the alcohol, in a comparatively short time, is converted into acetic acid; and so long as a supply of fresh air is kept up in the chamber, the spongy platinum continues to oxidize the liquid.

With a case of 12 cubic feet capacity, and 7 or 8 oz. of platinum black, 1 lb. of absolute alcohol may be acetified daily; and with a provision of 24 or 30 lbs. of spongy platinum, and a proportionate sized case, 300 lbs. of alcohol may be oxidized in the same time, producing an acid of the purest kind.

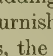
In every instance where alcohol or fermented alcoholic liquors are acetified, the principle of the conversion is the combustion of the alcohol of those liquors by combination with oxygen. This result is also attained when alcoholic liquids are exposed to the air at a slightly elevated temperature, in contact with a body in the state of fermentation, and in several other ways—which change has been called the *acetous fermentation*. In this manner wine, brandy, beer, and in fact all liquids which undergo the vinous fermentation, are converted into solutions containing acetic acid; and many liquids apparently pass at once into the acetous fermentation, especially those eviscerating a quantity of mucilage and very little sugar. Alcohol in a pure state does not suffer the acetous fermentation, but if it contains vegetable matter a metamorphosis occurs on its exposure to the air; hence the cause of the souring of wines, and the reason why weak ones do so sooner than strong, the former containing little spirit and much vegetable matter, while with the latter the reverse is the case.

In all cases of acetous fermentation, where a quantity of liquid is exposed to the air, oxidation takes place at the surface only, and this occasions the conversion of their alcohol into acetic acid to extend over several weeks, or even months. Heat very much accelerates the change, inasmuch as a portion of the alcohol is converted into vapour, and this, carrying with it some of the ferment in a state of eremacausis, communicates the same property to the vapour likewise, and acetic acid results; besides, imperceptible currents form in the liquids, by which fresh surfaces are always exposed till the work is completed. Spirituous liquors, on being exposed to the air in a state of fermentation, or with a ferment added to them, however clear they may be at first, speedily become turbid, and slimy filaments appear through the solutions, which gradually adhere and rise as a spume to the surface. When this spume incrassates, it precipitates to the bottom of the vessel, and is called *mother of vinegar*. During the formation of this body an elevation of temperature is observed, a peculiar aromatic odour is evolved, and an acid reaction acquired; towards the end of the operation the temperature falls to about that of the surrounding air, the liquor clarifies, and when it is siphoned off constitutes the well-known liquid, Vinegar.

It was formerly imagined that the formation of vinegar was accomplished by a peculiar fermentation, which was called *acetous*, in contradistinction to *lactic*, *vinous*, *butyric*, *mucic*, &c. It is now held by most chemists that, although in certain processes for the manufacture of vinegar fermentation takes place, yet this is rather the accompaniment than the cause of the chemical change.

At the close of the operation the nitrogenous organic matters contained in the liquor, and which have produced fermentation, are found at the bottom of the vat as a white, gelatinous, fungoid plant, to which the name of *Mycoderma vini* was given by Mulder. The experiments of Pasteur conclusively show that the presence of this fungus is essential to the formation of vinegar from alcohol solutions by the fermentation processes. It is also absolutely necessary that the spores should remain at the surface of the liquor. The plant may be sown by adding to the liquor a portion of a solution already containing the fungus. Where spontaneous acetification sets in it is because germs have fallen into the solutions from the air, where these and many others are almost always floating. The plant derives its nourishment from the albuminous matter and mineral salts contained in the mother liquor. Pure aqueous alcohol does not undergo acetification, however long exposed to the action of ordinary atmospheric air, because any germs which it acquires die for want of sustenance. When, however, Pasteur supplied the necessary nutriment by adding small quantities of ammonium phosphate (to furnish nitrogen) and alkaline and earthy phosphates, the atmospheric germs became fertile, and the alcoholic was converted into acetic solution. Fermentation also removes the too readily decomposable organic bodies, and is therefore essential to the production of saleable vinegar; but the amount of acidification depends entirely on the amount of alcohol which has been oxidized into acetic acid, and this oxidation appears to be entirely independent of those changes which merely result in the clarification of the liquor.

Buchen has shown that no *Mycoderma aceti* (*Mycoderma vini*) was to be found in the contents of a vat for oxidation of alcohol by air which had been in use for twenty-five years. The experiments of John Davy and Döbereiner tend to the same conclusion. The vinegar plant and allied vegetations probably act like spongy platinum and platinum black, rendering the oxygen more active by condensation in their pores in the course of their growth, and bringing it in an active state (? ozone) in intimate contact with the molecules of alcohol.

This view is still further borne out by the fact that ozone (probably triatomic oxygen, ) converts alcohol into acetic acid with very great rapidity. In 1869 Widemann erected a factory at Boston, U.S., to carry out this reaction commercially. His first idea was that the fusel oil in whiskey might be greatly reduced in amount by passing over it a stream of ozonized air. The results he obtained were surprising, and by the adoption of proper mechanical contrivances he so decomposed the whole of the fusel oil in maize whiskey, that in eight minutes the latter was, in the opinion of experts, equal to a spirit six years old. In 1870, 300 barrels of 40 gallons each were thus treated weekly, and the works were being extended.

He was naturally led to experiment upon diluted alcohols, and found that their oxidation was rapidly effected by ozone. He says:—"By adding water to maize whiskey and treating it as before, in almost as short a time (eight minutes) I obtained its complete conversion into vinegar." The best result was obtained by operating on a mixture of U.S. proof whiskey with seven times its weight of water.

On the 20th of April, 1871, works were opened at White Plains to manufacture vinegar by this means, which turned out from their commencement thirty barrels of vinegar daily, in a fit state to be immediately employed for pickling. In January, 1872, the same works were producing daily ninety barrels of vinegar of 40 gallons each.

Lavoisier's theory, that acetic acid is alcohol plus oxygen, and that the change effected by the so-called acetous fermentation is the oxidation of the alcohol, is now universally accepted by chemists.

Of all the volatile organic acids, acetic acid is the only one having the property of dissolving lead monoxide (PbO) and copper monoxide, forming basic acetates of these metals. The dilute acetic acid, or distilled vinegar used in pharmacy, should therefore always be examined for copper and lead, these impurities being apt to be contracted from the metallic vessels sometimes employed in the process.

Acetic acid exhibits the reactions of the fatty acids. It is not itself decomposed by electrolysis, being almost a non-conductor of electricity. A solution of potassium acetate is, however, split up by the voltaic current, with formation of dimethyl (ethane) and potassium carbonate:—

$$2KC_2H_3O_2 + H_2O = C_2H_6 + H_2 + CO_2 + K_2CO_3.$$

When exposed to a gradually rising temperature the vapour of acetic acid dilates abnormally, as may be seen from the following observations of Bineau:—

Degrees C.	Density.	Degrees C.	Density.
21	3·95	200	2·22
125	3·2	230	2·09
160	2·48	238	2·08

At 230° C. and upwards 1 atom of acid yields 2 volumes of vapour in accordance with the usual law. Beyond 238° the vapour undergoes no change of volume until the acid itself is decomposed.

Chlorine attacks acetic acid very slowly in diffuse light; in the sunlight its action is more rapid, chloracetic (C_2H_3ClO, Hofmann) and trichloracetic ($C_2HCl_3O_2$, Dumas) acids being formed. In like manner a mixture of bromine and acetic acid produces dibromacetic acid ($C_2H_2Br_2O_2$) in sunlight. Heated with bromine in a sealed tube, bromacetic acid ($C_2H_3BrO_2$) is formed, Perkin and Duppa.

Acetic acid is unaffected by nitric acid. Heated with sulphuric acid it is blackened, and carbonic acid and sulphurous acid are disengaged. Sulphuric anhydride dissolves in acetic acid, and if the mixture be kept for a few days at a temperature between 60° and 75° C. sulphacetic acid ($C_2H_4SO_5$) is produced.

When ferric chloride (sesquichloride of iron, Fe_2Cl_6) is added to acetic acid, and the acid then nearly saturated with ammonia, or if a neutral acetate is mixed with ferric chloride, the fluid acquires a deep red colour, owing to the formation of ferric acetate. Mercurous nitrate (nitrate of suboxide of mercury) precipitates mercurous acetate in white scales, which, on being heated, is partially resolved into metallic mercury. In presence of an excess of potassa, auric chloride (trichloride of gold, $AuCl_3$) is reduced on treating with acetic acid, and metallic gold deposited.

Acetic acid has been formed synthetically by Wanklyn and also by Berthelot. Wanklyn prepared sodium methyl ($NaCH_3$) by the action of sodium on a solution of zinc methyl in ether; he then passed into it a current of carbonic acid, when sodium acetate was formed:—

$$CO_2 + NaCH_3 = NaC_2H_3O_2.$$

Berthelot formed potassium acetate by heating acetylene dichloride ($C_2H_2Cl_2$) with aqueous potash to 230° C., or with alcoholic potash to 100° C. for ten hours:—

$$C_2H_2Cl_2 + 3KHO = KC_2H_3O_2 + 2KCl + H_2O.$$

The strength of glacial acetic acid is commonly estimated volumetrically by a standard solution of caustic soda. The change in the colour of the litmus not being very strongly marked, Rüdorff has proposed a new method, which he states to be very accurate, and which consists in determining the solidifying point of the acid.

WINE VINEGAR.—*Weinessig*, German; *Vinaigre*, French.—This species of vinegar is chiefly fabricated in wine-growing localities, or where grapes are abundant, from wines which have become acid, full flavoured wines giving the best table vinegar, the principal factories being at Orleans in France. The building where the work is carried on is called a *vinaigrerie*, and has always a southern aspect. The casks, called *mothers*, which are employed, hold from fifty to one hundred gallons, and rest upon strong wooden frames, supported by pillars of wood or stone of eighteen inches in height. Several such casks are placed in rows, and when acetification is carried on in the open air, eight, ten, fifteen, or twenty such ranks constitute what is termed a *vinegar-field*. Two holes are bored in the upper surface of the front end of each cask; the larger serves to charge the cask with wine, as also to draw off the vinegar when formed, and the smaller allows an influx or efflux of air as the cask is emptied or charged. The chief aim of the person who wishes to carry on a vinegar factory is to have a good fermenting-room, where the wines are exposed to an even temperature, having a copious supply of atmospheric air and free ventilation, in order to replace as rapidly as possible the air which has been exhausted of oxygen, and to carry off the carbonic acid set free, the air-holes for this purpose being constructed so as to admit of being closed in windy weather, or when the temperature of the room is depressed. The walls of the apartments are of brick, or some non-conducting material, and lined with lath and plaster.

Low-roofed apartments are the most suitable. When there is a high ceiling it is necessary to elevate the mothers, in order that they may occupy the higher strata of warm air. This trouble is dispensed with when the roofs are low. Experience has pointed out that in high-roofed apartments, where the tuns are placed at different levels, the uppermost work off quicker and better than the others. In the event of new mothers or vessels being used, it is needful to fill them one-third full with the strongest vinegar at a boiling temperature. This forms the stock, or true *mother*. The charges of wine added each time are two and a half gallons to every cask, and an interval of eight days is allowed for the acetification of each charge, before adding another of fresh wine. This treatment is continued—of charging and allowing eight days to work it off—till the casks are more than half full. One-third of the contents of each mother is then siphoned off—in some factories only 10 gallons—and run into the store tuns, and the process repeated anew of charging every eight days till the mothers are refilled, as before. Some manufacturers do not suffer the vinegar to remain in the mothers till they are two-thirds full, but siphon off at the end of every sixth or eighth charge 12 or 15 gallons of vinegar. The mothers should never be charged with more than the above quantity, in order to carry on a steady and efficient mode of acetification. Occasionally it happens that eight days are not sufficient to finish every charge. This is more unaccountable from the fact that the backward casks receive the same amount of care, and have the same temperature, as those which work well. It often occurs that the casks in the warmest part of the room are those which are backward, or *lazy*, as they are termed. In this event nothing remains but to empty such mothers of their contents and fill them with hot strong vinegar, when, on adding fresh charges, the acetous fermentation recommences and goes on as briskly as in the rest. Sometimes fresh quantities of a stronger wine and an increase of temperature are supplied, to quicken the fermentation in such casks, which mode is often successful. The *laziness* of the mothers is attributed to very vague and unsatisfactory causes, some regarding it as the effect of the electrical state of the casks and liquid.

It has been recommended to isolate the mothers as much as possible, and to use little or no iron in the construction of the casks. To ascertain if the liquor has fermented, the following experiment is resorted to:—A white rod, bent at one end, is plunged into the mothers and drawn out in a horizontal direction; if the rod be covered with a thick white froth—flowers of vinegar—the operation is said to be terminated; if the froth be reddish-brown, more wine is added, and the temperature increased till the whole is acetified. In summer the natural heat is sufficient, but in winter the mothers are heated by means of a stove to about 80° Fahr. (27° C.). The prevailing temperature should range between 75° and 80° Fahr. (24° and 27° C.). When proper attention has been made to the manufacture, the mothers usually work off double their contents of vinegar annually. The precipitation of the insoluble matters of ferment, the accumulation of *mother of vinegar*, and the deposit of tartar from the wine, fill the casks to such an extent that it is indispensable to empty the whole of them, and free them from these deposits every six or eight years; and often the entire factory needs renovation, but good casks will last for a period of twenty-five years.

The wine, if it be ropy, is introduced into a large tun filled with beechwood shavings, through a funnel opening in the cover, and allowed to repose for some time, whence it is afterwards drawn off by a tap in the lower part of the tun, and supplied to the mothers as required. Frequently, when weak wines are employed, from the proportionably large amount of vegetable matter they contain, it happens that the resulting vinegar is ropy and turbid; in these instances it is necessary to pass it through the clarifying or *fining* tun, and the advantage of having an average vinegar is gained.

The old method, introduced by **Boerhaave**, is still practised in Holland, in France, and on the Rhine. Two large tuns or vats, about 9 feet high and 4 feet in diameter, are supported on stands about 12 inches from the floor. Within 1 foot from the bottom of each vat is a perforated bottom, or wooden grate, resembling that of a riddle; on this a quantity of fresh cuttings from the vine, willow twigs, &c., is placed, and pressed closely together, the remainder of the vats being filled with *rapes*—the footstalks of the grapes—and light vine branches. Both vats are left open for the admission of the external air. They are then charged with wine; one is completely filled, the other only half. The two are left at rest for twenty-four hours at 75° Fahr. (24° C.), after which the half-filled vat is replenished from that already full, till the latter contains only half its contents of liquor. Twenty-four hours elapse before the liquid is transferred from the filled to the half-filled vat.

The process of transferring the liquid into the vats alternately is repeated every twenty-four hours until the vinegar is made. Towards the third or fourth day an internal effervescence is observed in the half-filled vat, which is accompanied by a sensible elevation of temperature, increasing gradually each successive day. On the other hand, the temperature and fermenting action of the filled vat are but sluggishly progressing, so that the intestine motion takes place only on alternate days in each vat. The completion of the process is known by the decreased temperature and abated action even in the half-filled vat. The vinegar is then drawn off into casks, and left in a cool situation till it clarifies. During summer the time occupied is fifteen days, but in winter the acetification extends over a longer period. The temperature of the half-empty vat should never exceed 80° Fahr. (27° C.); if it rises to 84° Fahr. (29° C.) the liquor is to be transferred every twelve hours, and an oaken cover placed on the half-filled vat in order to check the fermentation, otherwise the aldehyde, or half-made vinegar, will be dissipated, and only a vapid fluid remains, sour, but effete. If the whole be kept at 83° Fahr. (28° C.), and the menstruum transferred every twelve hours, the acetification will be effected in eight or ten days. According to DUMAS, the best French vinegar is made of good wine, which is put into a cask already containing vinegar, and to which atmospheric air has constant access. As acetification proceeds more wine is added at intervals, and when the whole has become vinegar it is drawn off to the amount of the wine used, and the process is repeated. Its strength, flavour, and colour depend upon the characters of the wine employed. The temperature of the factory is maintained at 86° Fahr. (30° C.). As the acetification becomes more complete the wine loses its peculiar odour and flavour, and acquires the sweet sharpness of vinegar. The weight of the liquor also increases. The absorption of oxygen, and its consequent conversion from the gaseous to the liquid state, causes a rise in temperature proportionate to the rapidity of the process.

MALT VINEGAR.—*Malz-Getreide* or *Bieressig*, German.—In this country the chief part of the vinegar is made from *malt wash*, or *gyle*, prepared by operating upon the materials in the annexed proportions:—Six bushels of good barley malt, properly ground, are mashed with 40 gallons of water at 160° Fahr. (71° C.), permitted to repose till the solid matter settles down, the solution drawn of, and a fresh quantity of water, say 40 gallons, at 180°, added to the residue, well agitated for a short time, allowed to settle, and then siphoned off as before. To take up all the soluble matters, the third washings may be performed with boiling water. On the whole, not more than 100 gallons of wash is to be used in extracting the soluble matters. When the solution has cooled to about 75° Fahr. (24° C.), it is well agitated with 4 gallons of yeast of beer; and after thirty-six to forty hours racked off into casks, and placed in the vinegar stoves or apartments, the temperature of which should range from 70° to 77° Fahr. (21° to 25° C.). The casks should be placed on their sides, the bungholes opened, and a circulation of air kept up in each cask by means of an orifice bored at each end of the cask, near its upper edge. Since the temperature of the liquid is somewhat less than the surrounding atmosphere, in consequence of the evaporation at the surface, an efflux of cold air takes place at the holes while the warm air enters at the bung, and thus a constant current is kept up.

This manufacture is frequently effected by *fielding*. In this case, as the term implies, the process is conducted in the open air. The casks rest on strong frames, one foot and a half high, being supported by firm pillars of brickwork or wood. Six or eight rows of these are arranged parallel to each other, with a narrow walk between each pair of rows; a sluice is placed along the casks into which the vinegar is siphoned, whence it flows into the store tuns in the magazine; and a flexible tube, or hose, supplies the *wash* from the great tun in the brewhouse. The bungholes are left open in dry, and are loosely covered with a tile in rainy weather. One-third of each *mother* is left empty for the circulation of air, so as to oxidize the alcohol as it generates in the wort. Three months are required to complete the process, and render the vinegar marketable.

The process of malting materially changes the character of the grain. The barley is steeped in water until it begins to swell, after which it is piled up in heaps (technically *couched*). Germination sets in, oxygen is absorbed from the air, producing a kind of slow combustion, accompanied by its necessary elevation of temperature. When this has proceeded far enough, further growth of the barley is prevented by heating the sprouted grain in suitable kilns. During germination a peculiar nitrogenous substance, termed diastase, is produced, which reacts on the starch of the grain, converts a portion of it into grape sugar (glucose, $C_6H_{12}O_6$), and renders it soluble, the starch taking up the elements of water:—

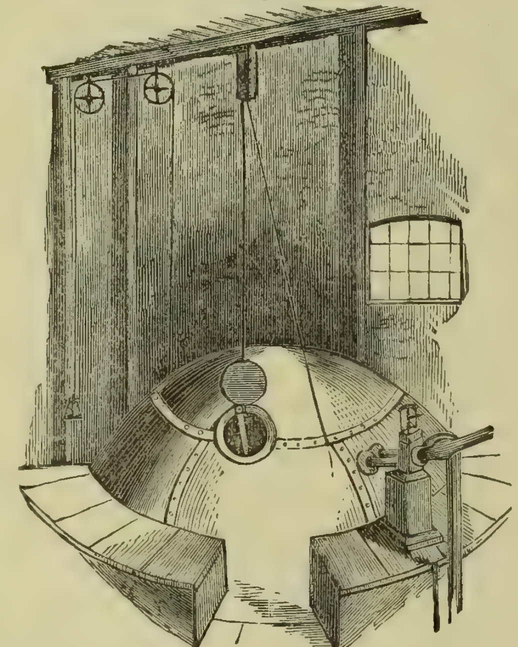
$$\overset{\text{Starch.}}{3C_6H_{10}O_5} + H_2O = \overset{\text{Glucose.}}{C_6H_{12}O_6} + \overset{\text{Dextrin.}}{2C_6H_{10}O_6}.$$

This conversion into sugar, called the *saccharine fermentation*, is the most important step in the preparation of beer, whiskey, and malt vinegar; for it is from this sugar that vinous fermentation produces alcohol, the parent of vinegar. Hence the early processes in an ale brewery, a malt distillery, and a malt vinegar works, are similar.

In the factory about to be described the malt is hauled up out of the waggons into the upper floors of the brewhouse. Here openings, placed in different directions, permit of the malt being poured down into the large bins, whence it is removed when a brewing is to commence. Vinegar-makers and distillers, as well as beer-brewers, give the name of *brewing* to the extraction of a saccharine liquor from malt. The quantity required for one brewing being measured out, and taken from the bins in sacks, it is poured through *hoppers*, or funnels, at the top of the grinding apparatus, by which the malt is reduced to meal. The apparatus consists of millstones and crushing-rollers, either or both of which can be employed as may be deemed advisable. In the one case a flat circular stone rotates and crushes beneath it the malt, which flows between it and a lower fixed stone: in the other the malt, after flowing through a shoot or trunk from the hopper, falls on a wire grating, where it becomes depurated. It then passes between two cast-iron rollers, rotating nearly in contact, by which means it is crushed into fragments. Various ingenious contrivances are adopted for stopping the circular motion of the rollers if any hard substance gets between them.

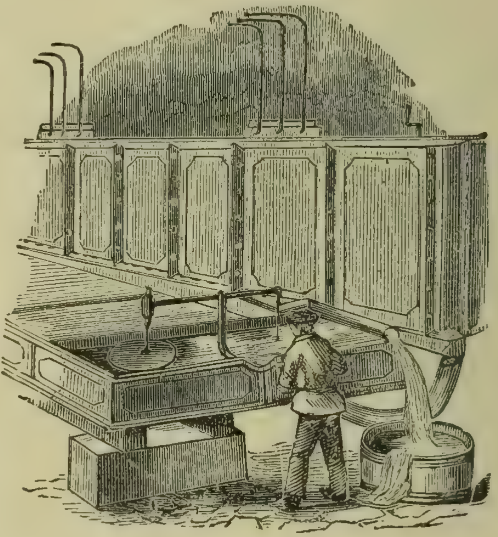
When the malt is crushed or ground, it falls through a hose or trunk into the mash-tuns in the floor beneath. These mash-tuns are similar to those used at large breweries and distilleries, but smaller in size. They are circular vessels, with a central *stirrer*, or instrument for keeping in constant agitation the ingredients contained in the tuns—the stirrer being worked by a steam-engine. It is in these vessels that the *saccharine fermentation* proceeds. The diastase, which is very soluble, acts upon the unaltered starch of the grain, and converts it into dextrin and grape sugar, as before mentioned. This grape sugar (sometimes also called glucose, dextrose, and maltose) is the sweet principle which subsequently yields to the brewer his beer, to the distiller his spirit, and to the vinegar-maker his acetic acid; and it may well be supposed that every precaution is taken, and every investigation made, as to the extraction of the greatest quantity and the most fitting quality of this important agent. The quantity of water required for a given quantity of malt, and the temperature at which the water is used, vary in each particular branch of manufacture, according to the strength of the *wort* required. The arrangements for settling these are very exact and ingenious. Hot water is let down upon the malt in the mash-tun when at the proper temperature; and in order to adjust this the foreman of the brewhouse ascertains, by the aid of a thermometer, the temperature of the water through a temporary opening in the upper part of the boiler. This is shown in Fig. 4, where is also represented a balance-weight and graduated scale, which, aided by a float on the surface of the liquid in the copper, indicates the depth of the water.

Fig. 4.



When the water has acted on the malt for a certain period, and been constantly stirred with it, the liquor receives the name of *wort*, and is allowed to flow through pipes out of the mash-tuns into a large cast-iron tank, or *underback*, measuring 24 feet or upwards in length, by 8 in width. This is merely a general receptacle for the wort, into which the latter is collected when the mashing is completed. *Cooling* is effected by various mechanical contrivances, which differ very greatly in different establishments. Large, open, shallow, airy rooms, called *coolers*, or *cooling-floors*, in which a thin layer of wort was cooled by the access of air on all sides, was the mode formerly adopted. This plan has, however, been superseded by contrivances, in which 100 square feet of surface is made to abstract as much heat as was formerly done by twenty times its extent. One of the *refrigerators* employed acts in the following way:—The hot wort is allowed to flow out of the underback into an oblong vessel, and out of this into another receptacle in the same part of the building. A continuous pipe, between 300 and 400 feet in length, passes backwards and forwards through the oblong vessel, and through this pipe cold water flows incessantly from an Artesian well 200 feet in depth. Constant currents of wort run in one direction through the apparatus, while a current of water in an opposite direction flows through the pipe which cools the wort.

Fig. 5.



The temperature of the wort may be cooled even to that of the water were it required, either by increasing its influx and retarding its efflux, or by permitting a larger quantity of water to flow through the pipe. The proper temperature is attained by regulating the relative streams of wort and water by suitably adjusted valves. Fig. 5 represents the refrigerator at the end where the wort enters, and where the water leaves the pipe, after having performed its office; collateral with the refrigerator is the under back. Not only does this method require much less room than that of the cooling-floor, but the refrigeration is greatly accelerated, and the manufacturer is rendered independent of the fluctuations of the weather; for since the water is brought from a source 200 feet below the level of the ground, it has, summer and winter, nearly the same temperature.

The wort produced differs from that made by the beer-brewer and distiller solely in possessing less saccharine strength. It suffers precisely the same process of fermentation.

From the refrigerator the cooled wort flows into the *jack-back*, a large circular receptacle sunk in the ground, whence it is pumped up into fermenting tuns. A valuable system of combination or centralization is observable in the arrangement of the conducting pipes. Large vessels are clustered, serving as a kind of common centre, from each of which openings lead to several other vessels, each orifice being regulated by a particular valve; for example, the liquid which, in various processes, is contained in the jack-back, has sometimes to be transferred to the fermenting tuns, at one time or other to a large back or cistern at the top of the building, and oftentimes to the copper; still there are not *three* openings from the back-jack for these several purposes, but *one*, which leads to a three-barreled pump, the barrels of which are respectively marked *tuns*, *back*, *copper;* so that, by turning one of three handles, the liquid can be conveyed to either one of these. Again, the back just alluded to is placed in connection with several other large tuns or backs, in different parts of the premises, to any of which its contents can be transferred by simply turning a handle. An hexagonal table is in one of the buildings, under the surface of which are six valves, all opened and shut by one key. On each tap the name of some particular vessel or building is inscribed, with which it is in adunation by an extensive series of subjacent pipes; and the overseer of this small piece of apparatus can control, in almost any direction, the flow of the liquid under manufacture.

The *gyle* is transferred from the fermenting tuns to other large casks, where it deposits, in course, a kind of acetous yeast—mother of vinegar; and being thence permitted to flow into the jack-back, it is drawn up one of the branches of the three-barreled pump into the large vat at the top; from this, as a centre, the gyle is allowed to flow into casks, where, after a longer or shorter period, it assumes the form of vinegar.

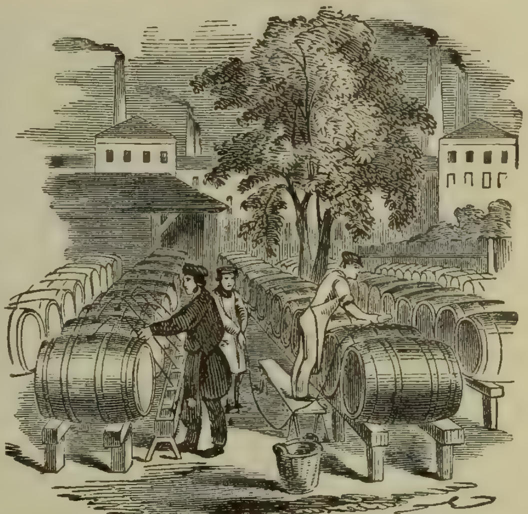
As before stated, transformation of the fermented wort into vinegar is effected at the factory in two ways, which are entirely opposite in their manner of operation. In the one case the casks containing the gyle are placed in close rooms, heated to a high temperature; in the other they are ranged in rows in an open field, where they remain many months. Different as these methods seem to be, yet the effect produced is precisely the same, namely, the conversion of the gyle into vinegar by the process of acetification, *i.e.*, the oxidation of the alcohol it contains into acetic acid. As regards the convenience and interests of the manufacturer, both methods seem to have their several advantages; for at many vinegar works both are followed, although one occupies a very much longer period of time than the other.

When *fielding* is resorted to, the gyle must be made during the spring months, and then left to finish during several months in the warmth of the season. The other process is technically called *stoving*, and in this case the casks containing the gyle are arranged conveniently in stove-rooms, and exposed to a certain temperature till the acetification is concluded. A cursory visit to one of these apartments readily convinces us of the progress of the manufacture by the pungent acetous odour of its atmosphere.

The fielding method requires a much larger extent of space and other utensils than the stoving, from the peculiarities always attendant upon it.

The casks, as already described, are placed in several lengthy parallel tiers, with their bung-side upwards, and left open. Beneath some of the paths which separate the rows of casks are pipes communicating with the "back" (vat) at the top of the brewhouse; and in the centre of each of these paths is a valve, opening into the concealed pipe. When the casks are about to be filled, a flexible hose is screwed on to this valvular opening, the other end of the hose being inserted into the bung-hole of the casks, and the liquor in the gyle-back at the brewhouse, by its hydrostatic pressure, flows through the underlying pipe and hose into the cask. The hose is long enough to admit of its reaching from the valve to all the casks in the same row, and is guided by a workman, as is seen in Fig. 6. After due time the vinegar is made, and is drawn off by the following ingenious operation. A long trough or sluice is laid by the side of one of the rows of casks, into which the vinegar is transferred by means of a siphon, whose shorter limb is inserted in the bung-hole of the cask. This trough inclines a little from one end to the other, and its lower end rests on a kind of travelling tank or cistern:

Fig. 6.

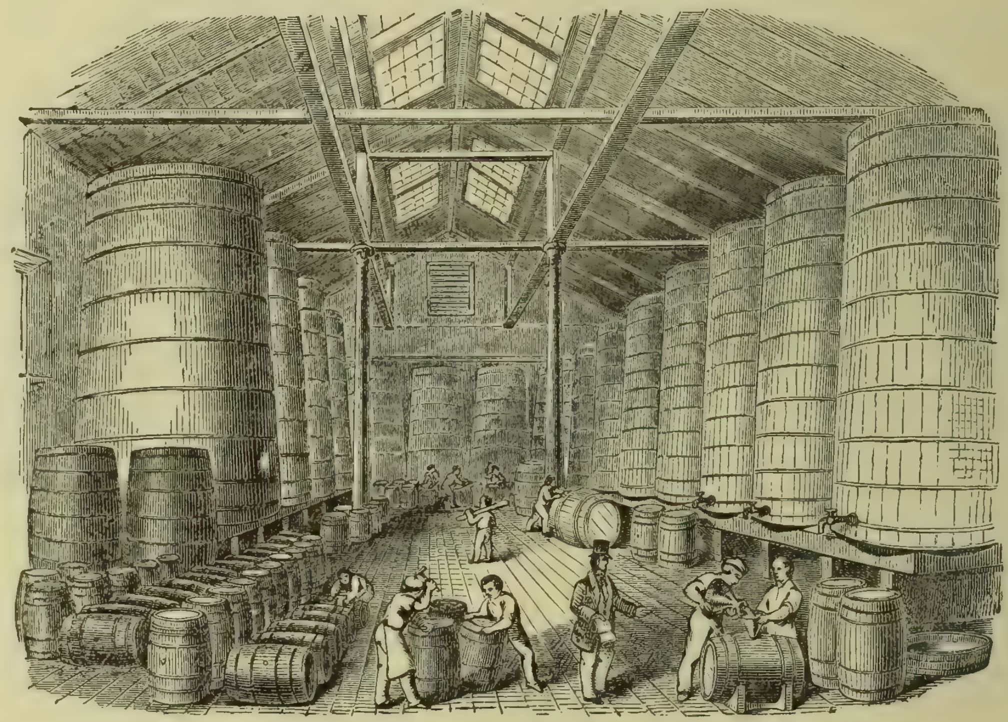


thus the vinegar from several casks is collected. A hose descends from the tank to the open valve of an underground pipe, which terminates in one of the buildings or stores. By means of steam power the pipe is exhausted of its air, causing the vinegar to flow through the hose into the valve of the pipe, and thence into the store-room. By this arrangement the whole of the vinegar is drawn off as it were invisibly. This arrangement is partly seen in the engraving. From the storehouse where the vinegar is received it is pumped into the *refining* or *rape* vessels, and filtered, to separate mucilaginous matter. These vessels are often filled with wood shavings, straw, or spent tanners' wood, but nothing acts so well in producing by filtration a clear bright vinegar as the stalks and skins of grapes, or raisins, technically *rapes*. The refuse of the British wine manufacture is very commonly employed.

It is a matter of so much difficulty to collect a sufficient stock of rapes to supply the filtering medium for large vinegar works, that, when once collected, no part of the materials relating to the factory are treasured with so much care.

Each "rape" or filtering vessel is fitted with a false bottom, on which the grape stalks are placed. Beneath the false bottom, and above the true one, a tap is inserted, which allows the vinegar to flow into a back or cistern. From this cistern a pump elevates the liquid to the top of the vessel. The filtering vessel is filled with vinegar, which filters through the raisin-refuse into the space beneath, from thence into the tank, whence it is pumped to the top of the vessel to recommence its circuit. Over and over again does this circuit proceed, the pump being kept constantly at work, and the vinegar incessantly in motion. The filtering substance gradually, but very slowly, wastes away, and is renewed from time to time.

Fig. 7.



By this process the last traces of alcohol become oxidized, all the coagulable nitrogenous matter and mucilage is removed, and the vinegar becomes transparent, or *bright*, as it is technically termed, and is then pumped into store-vats, where it is kept till required to be put into casks for sale. The "rapes" are immediately filled up with an equivalent portion of fresh vinegar, so as never to leave the raisin-refuse idle. The vinegar casks hold 116, 50, and 25 gallons, respectively. Each cask is examined and gauged before being brought into the *sending-out warehouse*, to see that it is sound and of proper dimensions. The warehouse is a large room, lined on all sides by store-vats, from which the casks are filled; after which they are finally coopered, branded, marked, &c., for the market.

The above description applies to pickling vinegar. Malt vinegar for household use is made in a somewhat different manner. The malt liquor is prepared in the usual way, at the temperature of 70° Fahr. (21° C.) and is then run into casks set on end, having each a perforated false bottom about a foot above the true one, upon which a layer of rapes has been previously placed. A small quantity of *argol*, or wine stone, the crystalline stony matter, chiefly tartaric acid, which is deposited during grape fermentation, is then added. After twenty-four hours the wash is racked off into another cask of the same description, and allowed to remain in this for a day or two, when it is drawn off into a third and fourth cask. After spending twenty-four hours in the last cask a portion of the liquid is racked off and supplied to the mothers. The remainder is then allowed to ferment quietly, as in the preceding instance, at a temperature of 70° Fahr. (21 C.). Argol communicates to it the appearance of wine vinegar. It is clarified by leaving it in the casks for some time with a little isinglass.

Pasteur in 1862 proposed a new method of making vinegar by the aid of the fungus *Mycoderma aceti.* A solution is first prepared suitable for the growth and propagation of the fungus, consisting of water with 2 per cent of alcohol, 1 per cent. of vinegar, and a small quantity of phosphate of potash, lime, and magnesia. The small plant soon covers the entire surface of the liquid, and at the same time the alcohol is acetified, upon which small quantities of wine, or alcohol and beer, are added until a sufficient bulk of liquid is obtained, upon which the charge is withdrawn carefully without disturbing the surface growth, and the apparatus used again as before. The vinegar thus prepared is said to resemble wine vinegar very closely in both aroma and flavour. The essential condition in Pasteur's process is careful attention to the growth of the plant. A vessel exposing 1 square yard of liquid surface, and capable of containing 10 to 12 gallons, yields daily 1 to $1\frac{1}{2}$ gallons of vinegar. The vessels preferred by Pasteur are shallow, and provided with lids; they may be square or round in shape; at opposite sides small holes are bored to admit air. The charge is introduced by tubes of gutta percha passing through the lids. These tubes are pierced laterally, beneath the surface of the liquor, with small holes. When the charge consists of wine or beer the fungi find sufficient nourishment; but when alcohol alone is used phosphates of lime, ammonia, potash, and magnesia must be added, so that the mother liquor shall contain about $\frac{1}{10000}$ of this mixture.

Sugar and Cider Vinegar.—In many factories, instead of a sweet wort of malt, a solution of sugar is often employed to produce vinegar. Several receipts are given for this department of the manufacture, the principal being the annexed:—Dissolve 10 lbs. of sugar and 6 lbs. of winestone (argol, *vide ante*) in 40 gallons of boiling water; put the solution into the fermenting tun, and when cooled down to 80° Fahr. (27° C.) add 4 quarts of beer yeast, and agitate the whole thoroughly. Grant the liquid repose for six or eight days at a temperature of 65° Fahr., till the vinous fermentation is ended; after which rack it off and submit it to one or other of the processes already mentioned, or by the *graduator* process, presently to be described. Another prescription is—

100 parts of water,
13 parts of brandy,
4 parts of honey,
1 part of tartar,

or

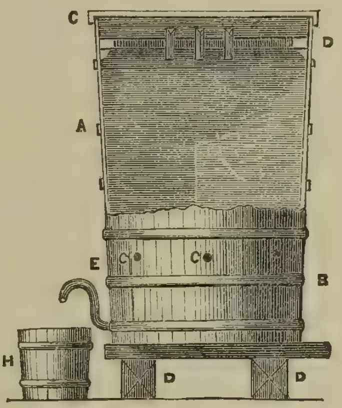
120 parts of water,
12 parts of brandy,
3 parts of brown sugar, and
1 part of tartar,

treated as before directed.

Quick Vinegar Process.—*Schnellessigbereitung,* German.—From the length of time necessarily occupied in making vinegar by the above methods, the name of *slow vinegar process* has been given to the manufacture since the discovery of a quicker mode of accomplishing the same end. Of the older methods, the only approximation to the process now to be considered was that of Boerhaave, already mentioned. Good vinegar is at present made from alcoholic liquors in the course of thirty-six or forty-eight hours. The slow and quick processes are conducted upon the same principle, namely, the oxidation of the alcohol; but the manner in which it is oxidized is different—the surface exposed in the quick method being many thousand times more extensive than in any former one.

When the oxidation of alcoholic solutions is slow aldehyde is the principal product. Aldehyde, however, absorbs oxygen with great avidity; hence, if the supply of oxygen be abundant, it is in the moment of fermentation converted into acetic acid.

Fig. 8.



In 1823 Schützenbach conceived the idea that by greatly enlarging the relative surfaces of contact of the alcoholic solution and air containing oxygen, the process of acetification would be greatly facilitated. His experiments proved successful, and soon after the German or quick vinegar process was generally adopted, especially in Germany and other countries where no duty is imposed upon alcohol.

The principle involved in the apparatus of course depends on an extreme division of the liquor being effected. This is very skilfully contrived. By making the solution percolate slowly through and diffuse over a mass of shavings, it forms a very thin liquid layer, the surface of which is exceedingly large, and is therefore better adapted for the chemical appropriation of the oxygen in the current of air which is transmitted over it. A gallon of liquor, if allowed to percolate slowly through the apparatus about to be described, offers a surface of about 100 square yards to the action of the air during its descent.

The vinegar generator, technically "graduator"

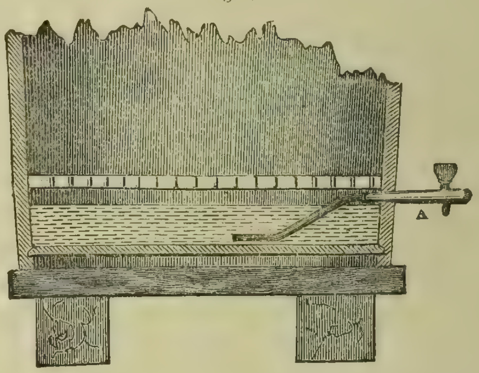
(Fig. 8), is a large tub or tun, A, of oak, of varying dimensions. In England the tun is often 13 feet high, 15 feet wide at the bottom, and 14 feet wide at the top; in Germany the size is usually much less, though the advantage to the manufacturer from the greater surface exposed in the large vessels is very great. The tun rests upon a stage, *d d*, of wood or brickwrok, 1½ foot high. A stout hoop of beechwood, upon which rests a perforated shelf, is fastened in the interior of the tub at B, 18 inches from the bottom, and 2 inch above this are eight or ten holes, *c c*, 1 to 1½ inch in diameter, bored at equal distances round the cask, and inclining downwards from the outside. Another strong beechwood hoop, D, is fixed 1 foot from the top of the tub, on which is placed a second perforated disc, pierced with holes 1 inch apart and ¼th of an inch in diameter. These apertures are loosely filled with cotton wick or packthread, a knot being made at the top end to keep them from falling through the cover. The threads pass down to the shavings, and serve the double purpose of conducting the liquor equally through the body of the tub, and also of stopping it from passing too rapidly through the tun. The space between the perforated shelves is filled to within a few inches of the top with shavings of deal or broken beechwood, which have been well washed with boiling water and afterwards stove-dried. Charcoal is sometimes used, and from its marvellous power of condensing oxygen in its pores, as well as the large surface it exposes, it is probably the best medium that can be employed. A thermometer is introduced a little below the top cover, the bulb of which reaches the middle of the apparatus, to indicate the rise or fall of temperature, as the subsequent oxidation of the alcohol is greater or less. Six larger holes are bored in the upper cover, 1½ inch in diameter, into which wooden or glass tubes, opening below it, and about 9 inches long, are adjusted; these serve as chimneys to carry off the deoxidized air from the vessel. A loose oaken cover, C, with a funnel opening in the centre, through which the liquids for charging the generator are supplied, protects the whole from dust. At 1½ or 2 inches from the bottom of the generator a pipe or glass tube, E, is inserted, which bends upwards nearly as high as the lower perforated shelf, and then curves downwards, so as to discharge the liquid when it rises so high as the shelf in the interior of the vessel, into an appropriate vessel placed to receive it. In the lower part of the vessel (Fig. 9) is fixed a wooden pipe, 12 or 15 inches long, and fitted with a plug or screw to act as a tap, by which to run off the dregs and other albuminous matters when they accumulate.

Everything being thus arranged, hot strong vinegar is poured through the funnel opening into the outer cover, and passed through the generator for one or two days, to sour the shavings and sides of the generator before passing the fresh spirituous liquors through for acetification.

To fill the tun a standard liquor is taken, consisting of 50 gallons of brandy or whisky, of 60 per cent. by volume, and 37 gallons of beer or malt wort, with about $\frac{1}{1000}$ of ferment. Acetification takes place slowly in the beginning; but as the shavings become gradually covered with the fungus of the *Mycoderma aceti*, or in the workman's phrase, impregnated with *mother of vinegar*, the oxidation is accelerated, and the larger the amount of the fungus the quicker the oxidation; so that the process goes on improving. The composition of the mixtures used varies very much; sometimes 5 gallons of the above liquor are mixed with 40 to 50 gallons of weak vinegar, and passed through the vessel at a temperature of 80° Fahr. (27° C.), and by this means the alcohol is more readily oxidized; or a liquor containing 1 part of alcohol, sp. gr. 0·850, 6 parts of water, and a trace of honey, yeast, or wort, may be used. According to Wagner, one of the mixtures very generally used is made up of 4½ gallons of proof brandy, 9 gallons of vinegar, and 26 to 27 gallons of water, to which has been previously added a liquid made by soaking a mixture of bran and rye meal in water, in order to promote the growth of the fungus *Mycoderma aceti*.

It is well known that essential oils, or a mere trace of wood vinegar, or any kind of tarry or empyreumatic matter, entirely arrest acetification; consequently, the vinegar used must be quite free from pyroligneous acid.

Fig. 9.



The tun being thus brought into a proper state of working, 15 to 20 gallons of the standard liquor previously mentioned are diluted with 60 gallons of soft water, and poured into the tun through the funnel in the outer cover, and permitted to pass through; it is again returned to it, unless there be several generators in the factory, in which case the liquor, after passing through the first, is allowed to percolate the second tub. Every succeeding hour 2½ gallons are drawn off from the second tub, that of the first being kept as vinegar, while the product of the second is always returned to the first vat or generator; thus, in twenty-four hours 30 gallons of vinegar are ready for sale: 150 gallons of superior vinegar can be manufactured daily in ten tuns, which one man can superintend. From the purity and clearness of the product, it resembles distilled vinegar; but to improve the colour and flavour, and render it more marketable, one pound of cream of tartar, and two pounds of brown sugar or molasses, is sometimes added to every 50 gallons, to suit the taste of the buyers. If honey or molasses has been previously added to the spirituous liquor, a fine coloured vinegar is at once obtained, hence this addition is often made for the sake of economy.

The temperature of the rooms should be 100° Fahr. (38° C.), and that of the standard liquor 125° to 130° Fahr. (52° to 55° C.) when poured in. After the working tuns have acquired a proper state for the acetification of the liquid, the charging liquid should always be run in at 78° to 80° Fahr. (26° to 27° C.), and the temperature of the room kept at 70° Fahr. (21° C.). During the time the solution is percolating the temperature of the generator rises to 100° to 108° Fahr. (38° to 41° C.), from the rapid oxidation of the alcohol, as will be indicated by the thermometer if the operation is going on favourably, so that if the quantity of liquor dealt with be large, it is not necessary to raise the temperature artificially. If a stronger acid be required than the product of the first and second vessels, the mode adopted is to mix the vinegar made in the first and second tuns with a stronger alcoholic liquor, and pass the mixture through a third tub; and if, when transmitted, it should be required still stronger, a fresh quantity of alcohol is added, and submitted to a fourth tub, to obtain acid of the strength required. The vinegar procured in this way, from the first and second tuns, should require 30 to 36 grains of pure potassium carbonate to neutralize the acid in every fluid ounce; that from the third tub, after being mixed with 20 gallons of the standard liquor, instead of 16 or 18, should neutralize 45 grains, and that from the fourth generator may be made to contain so much acetic acid that 1 ounce will saturate 60 grains of the pure alkaline carbonate.

When thick muddy liquors, or those containing much organic substance, such as beers or other mucilaginous liquors, are filtered through the tuns, their dregs deposit on the chips, the accumulation of which prevents the proper diffusion of the liquid through the generator, and consequently the complete oxidation of the alcohol is retarded. Should this happen, the chips are withdrawn from the generator, washed with hot water, and then after being steeped in hot strong vinegar, as in the forementioned instance, returned to the tub; or a stream of hot water, and afterwards a stream of hot strong vinegar, is made to pass through the tun without taking out the shavings; and afterwards hot strong vinegar, as before stated. It is better, however, always to charge the tuns with liquors free from sedimentary or slimy matters. Any such liquors ought to remain a sufficient time in the clarifying vessel to become bright before submitting them to acetification. Where these precautions are observed the tuns do not require frequent cleansing, and the products are purer and better. As before stated, many makers employ pieces of charcoal, about the size of a walnut, which have been deprived of their saline ingredients by dilute hydrochloric acid, and afterwards of the acid by water. The charcoal effects the oxidation of the spirit much more quickly than the shavings, and does not become so soon choked with slimy and other deposits: in a measure it also replaces the *Mycoderma aceti* by its condensing action upon the alcohol and aldehyde vapours and oxygen, and is itself competent to acetify the liquids, though not as energetically as spongy platinum and platinum black.

All the liquors spoken of in describing the *slow processes*, and indeed any alcoholic liquor free from empyreumatic products, may be converted into vinegar by this method.

The *wine malt* for charging the generators is made from wheat and barley malt, mixed in the proportion of 40 pounds of the former to 80 pounds of the latter. The whole is first well ground, then saturated with 40 gallons of water at 120° Fahr. (49° C.), and allowed to settle; the clear supernatant liquor is then drawn off. The residues are treated with water at 160° Fahr. (71° C.), agitated, and after settling, the clear solution drawn off as before: a final extraction of the soluble portions of the grain is made with water heated to 200° to 212° Fahr. (93° to 100° C.). The whole of the washings should not exceed 110 gallons. The solution is cooled to 75°, and 15 pounds of yeast added to it with much stirring, and the whole left at rest in an atmosphere of 80° (27° C.) for five or six days to undergo the vinous fermentation, after the termination of which it is ready for the generators.

Although this method is seemingly the perfection of rapid acetification in the vinegar manufacture, yet without proper care it is subject to many losses. In the slow methods, from the lengthy exposure to the atmosphere, a large quantity of material is evaporated and lost, even at the comparatively low temperature employed. The elevated temperature of the generators, of course, tends to increase the amount of this wasteful evaporation, and to completely carry off the alcohol and aldehyde; it has indeed sometimes happened that not a trace of acetic acid has been left at the termination of the process. When the quick vinegar-making process was first introduced great losses were experienced from the escape of the extremely volatile aldehyde (at that time unknown to chemists). Aldehyde boils at 68° Fahr. (20° C.). On this compound being discovered chemists at once saw that the cause of the deficiency was its imperfect oxidation, an evil immediately remedied by increasing the number of holes in the generator, so as to admit a larger supply of atmospheric air, in order that the whole of the volatile aldehyde might be converted into the more fixed acetic acid (which boils at 243° Fahr., 117° C.), before it has time to escape from the tun. This is one of the multitudinous instances of the advantages to be derived by the manufacturer having a knowledge of chemistry; and, moreover, is a happy illustration of the value of scientific investigation. All our records of the past show that every discovery of the chemist and physicist at some time or other plays its part in perfecting human civilization, however useless it may at first sight appear. The formation of aldehyde may be shown by closing some of the openings which serve to supply air to the tun; and when the alcoholic liquor has passed through, applying a solution of strong potassa to a portion of the clear liquid, upon which a brown resinous mass is obtained. This is one of the most characteristic reactions of this body. Another test for aldehyde is its power of reducing silver oxide to the metallic state. If some of the solution from the generator (when not doing its work thoroughly) be boiled in a test tube with a little oxide of silver, decomposition ensues; part of the oxide of silver is reduced to metal, and forms a brilliant and uniform coating on the glass; the solution remaining contains silver acetate.

The specific gravity of aldehyde is 0·790; it is a limpid, colourless liquid, very inflammable, and possesses a peculiar characteristic etherial odour.

From these facts it may be seen that the regulation of the supply of air to the vats is the most important of all the cares of the vinegar-maker.

If the supply be too great, the oxidation of the spirituous liquors will be too rapid, and from the consequent rise of temperature (probably to 120° Fahr., 49° C.) much alcohol will be lost. On the other hand, an insufficient supply of air stops the process half-way, and the manufacturer produces aldehyde instead of acetic acid. Theoretically, 1 per cent. of alcohol by weight should yield $1\frac{1}{10}$th per cent. of anhydrous acetic acid, or as much acetic acid per ounce as will neutralize 5 to 6 grains of pure potassium carbonate. In practice it is found that 200 gallons of spirit of 50 per cent. yield 1667 gallons of vinegar, neutralizing 32 grains of the alkaline carbonate per ounce, or 1775 gallons of 30 grains neutralizing power. According to theoretical calculations 1900 gallons of 30-grain vinegar should be obtained, which shows a loss in manufacturing of about 6 per cent. In many factories much of this loss is obviated by causing the vapours from the acetifying tuns to pass over a surface of cold water, in order to absorb any escaping alcohol or aldehyde. This water is afterwards used in extracting the soluble matters from fresh quantities of malt.

Some of the London vinegar works use a very large slightly conical tub or tun, 14 feet wide at bottom, 15 feet at top, and 13 feet high. Two and a half feet above the bottom of this tun a false one is laid; the space over this bottom is filled with coopers' wood shavings and chips, and the space beneath is destined to receive the liquor as it trickles down on the true bottom, in order to be pumped up in continual circulation. The reservoir of the wash is placed at a moderate elevation. The liquor discharges itself through a regulating stopcock or valve into a pipe which passes down through a suitable hole in the middle of the lid of the generator, and terminates a few inches under it, in a cross pipe shut at the ends, which is made to revolve slowly by mechanical power in a horizontal direction, round the end of the vertical pipe. This cross pipe is long enough to reach nearly to the sides of the tun, and being pierced with small holes in its under side, delivers the fermented liquor in minute streams equally all over the surface of the chips of wood. The wash falls thence into the lower part of the tun, through holes round the circumference of the false bottom; afterwards it is pumped up again, under certain modifications to be presently described. The air for oxygenating the alcohol into vinegar is supplied from two floating gasometers, which are made to rise and fall alternately by steam power. The ascending one draws its air from a pipe which passes into the centre of the tun, immediately under the false bottom, and as it redescends it discharges the air through a pipe into a cistern of water, which condenses and retains the alcohol vapour drawn off with the air. This water is used in making the next acetifying mixture. Fresh air is admitted into the top of the tun by the sides of the vertical liquor pipe, which is somewhat smaller than the hole through which it passes. Proper valves are placed upon the pipes connected with the gasometer pump, so that the air drawn off from the bottom compartment is prevented from returning. A small force pump is employed to raise the liquor continuously from the bottom of the tun to the cistern overhead. By this arrangement good vinegar is made in a few days without any perceptible loss of materials. The progress of the acetification in this apparatus is ascertained by testing the air for oxygen, as it is slowly drawn into the gasometers or expelled from them. For this purpose a bundle of twine, which has been impregnated with a solution of acetate of lead and dried, is set fire to and plunged into a bottle filled with the air, which should contain so little oxygen as to be unable to maintain the combustion.

By regulating the warmth of the apartment, the motion of the gasometer, and the admission of air, the due progress of the acetification may be secured. The vinegar has an average strength of 5½ per cent. of hydrated acetic acid, and is immediately ready for market.

Another process, not very unlike the preceding, patented by Mr. Ham, of Bristol, so far back as 1824, is still in operation at several works. The apparatus consists of a large vat, in the centre of which is placed a revolving pump, having two or more shoots pierced with holes, so as to cause a constant shower of wash—fermented wort—to descend from the top when they are set working. The lower part of the vat is charged with wash, the upper part with birch twigs, piled as high as possible, but without interfering with the revolution of the shoots. Between the surface of the wash and the joist which supports the birch twigs, a space of 3 or 4 inches is left unoccupied, and one or more holes perforated therein, in order to admit a current of air, either direct from the atmosphere, or from a blowing apparatus. If the wash be maintained at a temperature between 90° or 100° Fahr. (32° to 38° C.) and the pump kept in continual motion, a charge may be acetified in a period of two, fifteen, twenty, thirty, or forty days, according to the quantity of liquid and the mass of twigs through which it has to pass; but generally the birch twigs and liquid are so proportioned as to obtain the acid in fifteen or twenty days. The advantages offered by this arrangement are, that a wash made from raw grain with one-sixth of an admixture of malt will yield a vinegar equal to that from malt alone; besides this, any other liquor capable of fermentation and producing alcohol can be acetified as in the German process. The acetification can be arrested at any moment, and the current of air increased or diminished at will.

Messrs. NEALE and DUYCK, of London, patented a process for the manufacture of vinegar from beetroot in 1841. The method given by them is the following:—The tops and shoots of the beet are cut off, and the roots, after being thoroughly washed, are rasped into a fine pulp, with which a number of strong cloth bags are filled. These bags are placed in a powerful press, with a board or hurdle between every two, and subjected to pressure till the whole of the saccharine juice is extracted from the pulp. The strength of this juice varies from 7° to 9° of the hydrometer, and must be reduced by the addition of water to 5°. The liquid is then boiled for a short time and the *wort* removed to the coolers, in which it remains until the temperature falls to 60° Fahr. (45° C.). It is next conveyed to the fermenting vat, half a gallon of yeast being added to every 100 gallons of the wort. When fermentation has ended, the wash is pumped into the acidifying vessel, and is there converted into vinegar. The acidifying vessel consists of a strong vat, capable of containing 24,000 gallons, in the centre of which, a short distance above the bottom, a rose, or small inverted dome, is fixed, pierced with numerous small holes, and communicating by a pipe with a blowing apparatus. Upon the bottom of the vat lies a steam worm, one end of which is connected with a steam boiler, and furnished with a steam-cock, the other end being open to the atmosphere.

The interior of the vat is divided into several compartments by means of diaphragms or perforated false bottoms, and the cover of the vat is provided with a valve which opens outwards upon a very slight pressure from within. The vat is likewise furnished with a thermometer, the bulb of which is immersed in the liquid contained in it, by which the temperature of the liquid is known.

The mode pursued for converting the fermented wash into vinegar, by means of this apparatus, is as follows:—2000 gallons of vinegar are first let into the vat, to serve as *mother* to an equal quantity of fermented wash, which is introduced at the same time; and a little yeast being added, the whole enters quickly into the so-called acetous fermentation. After the action has commenced, air is forced into the apparatus by the blowing machine, which air, in its passage through the small holes in the false bottoms, is brought into intimate contact with the liquid, imparting to it a portion of its oxygen; the deoxidized air and carbonic acid evolved from the vinous fermentation being expelled through the valve in the cover, by the force of the current which is instituted through the vat. When the temperature, as indicated by the thermometer, falls below 70°, a current of steam is admitted into the worm by turning the cock, so as to maintain the heat of the vat at between 70° and 80° Fahr. (21° to 27° C.). By this means the liquid will in a few days be converted into vinegar; an additional 4000 gallons of the fermented wash are then introduced, and the preceding process continued; in a few days the whole 8000 gallons are converted into vinegar. Fresh charges are continually added and acetified, as just mentioned, till the vat contains 24,000 gallons of vinegar. When the acetous fermentation of the last charge has ceased, 8000 gallons of vinegar are drawn off, and fresh wort added, acetified, and drawn off alternately, about 16,000 gallons of made vinegar being always kept in the vat.

FRUIT VINEGAR.—Apples, grapes, and other saccharine fruits are expressed, the juice, with the addition of a little yeast, set aside in casks in a warm place—75° to 80° Fahr. (24° to 27° C.)—until the vinous fermentation has ceased, and then acetified by any of the preceding methods.

A very superior vinegar is made in Germany and other continental states from grape-sugar and the spirits produced from potatoes, beets, and molasses. The excise laws of England, however, prevent the adoption of these materials, except under heavy duties.

In some factories large quantities of sour ale and beer are converted into vinegar; but the product is much inferior to the vinegar made from wine or malt wort. The large amount of nitrogenous and other extractive matters which those liquids contain undergoes a second or putrid fermentation after the alcohol has been oxidized into acetic acid, and in doing so reacts upon the acid, leaving a liquid of a disagreeable odour, slightly resembling very stale beer. By addition of sulphuric acid this second fermentation is postponed for some time, but the vinegar has nevertheless a nauseous smell, which renders it objectionable.

Mr. J. C. KENT, of Upton-on-Severn, states that when he first undertook the supervision of the manufactory of Messrs. KENT & SONS, the firm was in the habit of buying beer, ale, and porter, that had gone hard and sour, for conversion into vinegar; and on one occasion the bankrupt stock of a large brewery at Cavendish Bridge, in Derbyshire, was bought. Murmurs had reached them on several occasions that the vinegar, on being kept, lost its acidity; but when the above large quantity of beer came to be sent out as vinegar the complaints became loud and frequent. It was found that the putrid fermentation of the beer was the cause of the mischief, and since that time no sour ale has been purchased by this firm. Some of the returned vinegar became exactly like vapid beer, less putrescent as to smell, but nevertheless in a phase of putrid fermentation. Mr. KENT also states that, in his opinion, it is impossible to make good vinegar from beer; and further, that although one or two manufacturers claim to be able to dispense with the addition of sulphuric acid to malt and grain vinegar, as mentioned further on, he has never been able to obtain a sample free from this acid.

Dr. STENHOUSE, in an investigation on sea-weed, has shown that when such bodies are caused to ferment in presence of lime, at the temperature of 96° Fahr. (35°·5 C.), acetic acid is generated in large quantities, and is, after subsidence of the action, found united with the alkaline earth in the form of acetate of lime. In three experiments with different varieties of sea-weed, he obtained as a result an average quantity of 1·8 per cent. of anhydrous acetic acid. He employed a temperature of 96° Fahr. (35°·5 C.), and added hydrate of lime gradually, keeping the mass slightly alkaline, till the fermentation ceased; after which the liquid was filtered off, evaporated to dryness, and the residue heated (to decompose the mucilaginous matters), when crude acetate of lime remained. This process has never yet been carried out on a manufacturing scale, although in some of the northern countries of Europe, as well as on some of the Scottish and Irish coasts, where sea-weed is plentiful, vinegar might be profitably produced.

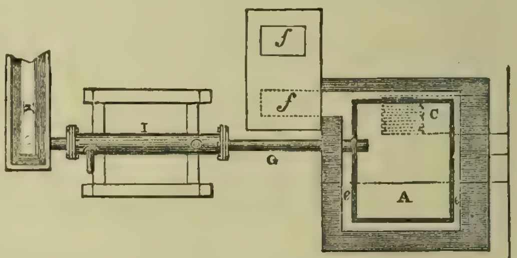
PYROLIGNEOUS ACID, or *Wood Vinegar.*—*Acĭdum Pўrolignōsum*, Latin; *Holz-säure*, or *Holz-essig*, German; *Acide pyroligneux*, or *Vinaigre de Bois*, French.—The term pyroligneous acid is purely technical, and merely implies the crude acetic acid, contaminated with various empyreumatic oils, which is obtained from wood by destructive distillation. All organic bodies, except those which sublime without change, are decomposed when exposed to heat in closed vessels, their constituents interchanging with each other and forming new compounds, which are of sufficient stability to resist the particular temperature employed. Thus the elementary components of wood, after a certain amount of heat is applied, arrange themselves into combinations quite distinct from those in which they originally were. Some of these are gaseous; but at moderate temperatures by far the greater part are liquid, the quantity of the latter depending entirely upon the greater or less degree of heat applied in the distillation.

The main cause of decomposition of such an organic body as wood by heat is, that the strong affinity of its contained oxygen for carbon and hydrogen, and the comparatively great stability of the more simple compounds of these bodies, causes their formation immediately that there is a sufficient amount of commotion created amongst the atoms of the original body to allow them to commingle freely. Heat sets up the necessary amount of vibration, and those compounds are at once formed which can resist, without rupture of their constituents from each other, the multitude or amplitude of the vibrations corresponding to the temperature at which they are evolved.

As a general rule, those bodies containing much oxygen are decomposed at comparatively low temperatures. Acetic acid is an exception; as has been before observed, a dull red heat does not cause its constituents to fly sufficiently apart from each other to cause their total separation, and the compound therefore remains unchanged. To this circumstance is due the large amount of acetic acid which is produced during the destructive distillation of wood. The composition of wood may be taken as $C_6H_{10}O_5$ (or $C_{18}H_{30}O_{15}$) cellulose, also called lignin. The hydrogen and oxygen being in the proportions to form water, the withdrawal of carbon would form acetic acid thus:—$2C_6H_{10}O_5 - 2C = 4C_2H_4O_2$. As might be anticipated, acetic acid is amongst the earliest and most abundant products of the distillation of wood, and being volatile, escapes decomposition at the higher temperatures employed later. As the distillation progresses, marsh gas (CH_4), olefiant gas (C_2H_4), tetrylene (C_4H_8), and volatile oils, such as benzol (C_6H_6), toluol (C_7H_8), naphthalin ($C_{10}H_8$), paraffin ($C_{20}H_{42}$), phenol (C_6H_6O), &c., are given off. At the close of the operation nothing but charcoal remains. The actual facts which are observed in the distillation of wood are as follows:—First, the water passes off, which is extraneous to the wood; secondly, the wood itself is decomposed, and gives rise to water and the crude acetic acid, which is next eliminated; thirdly, condensable matters containing an excess of carbon, forming the tar and oily substance, pass over; and lastly, towards the close of the distillation, carbonic oxide and marsh gas are evolved, leaving in the retort a charcoal similar in form to the wood introduced.

The distillation of wood is carried on in large cast-iron cylinders, or in square ovens made of stout sheet-iron, riveted firmly together, the heat being applied to them directly. A convenient apparatus for the distillation of wood is sketched below. Fig. 10 is the plan, and fig. 11 the elevation of the apparatus. In these figures, A is a box made of cast-iron plates, firmly bolted together, of the capacity of 100 cubic feet. This box is imbedded in brickwork. B is a cover on the upper end of the box, through which the charge of wood is introduced, another such opening being at the opposite side (not shown in the figures), and is made air-tight by a cover such as B. Through this second door the charcoal is withdrawn. C, the firebars; D, the firedoor, through which the fuel is introduced; *e e*, the spiral course of the flame round the box, and *f f*, the flue passing into the chimney.

Fig. 10.



The iron pipe, G, conducts the gases and other volatile matters evolved to the condenser, which consists of a series of pipes, I, I, I, of large calibre, through which the pipe, G, passes, leaving a surrounding space through which cold water constantly flows. The pipes rest one above the other on a wooden framework, H. Through L a stream of water from the tank, K, enters the lower condensing pipe, and flows thence into the others by the connecting pipes, *o o*, till discharged by P, at a temperature reaching ebullition. Part of the distilled vapours and gases, in their progress downwards, condense into a liquid, which falls into the air-tight tank, S, and is thence conveyed by the connecting pipe, T, into another tank, collaterally placed, but at a lower level. V is a tube from the pipe G, projecting into the furnace, through which the uncondensed carbonaceous gases flow into the fire, where they are utilized as fuel. When the distillation has fairly commenced, these gases serve to maintain almost sufficient heat to effect the decomposition of the charge.

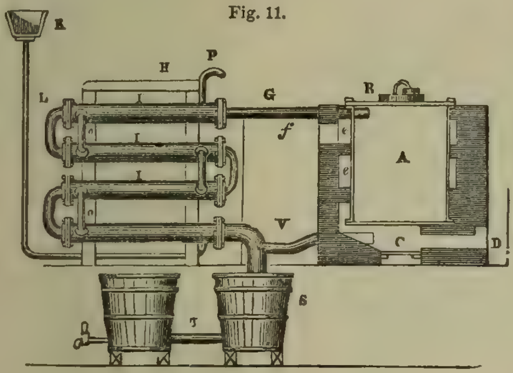


Fig. 11.

The usual time allowed for carbonizing each charge is twenty-four hours. After the wood is exhausted, the fire is withdrawn from the oven for six hours, so that the apparatus may cool, to allow the charcoal to be abstracted through the opening at the back, airtight sheet-iron boxes being placed beneath the door to receive it—100 cubic feet of beechwood produce 60 per cent. of charcoal, as much brushwood being used to obtain the heat required to carbonize the wood.

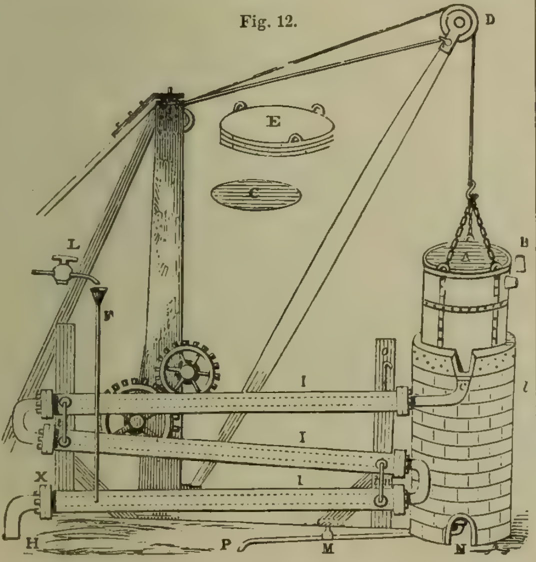


Fig. 12.

The apparatus in use at Nuits and Rouen, in France, is the following:—In Fig. 12 A is a large sheet-iron cylinder with an opening in the upper part of one of the sides, into which an adapter, B, is introduced; C is the cover of the cylinder, fitted tightly to it with bolts and screws. The cylinder being charged with wood, the cover, C, is fixed tightly in its place, and the cylinder hoisted by means of a crane, D, fixed adjacent to the furnace, and deposited in an upright cylinder of brickwork which may be covered, at will, by means of a dome, E, made of brickwork. The cylinder is charged with wood and deposited in its receptacle, and the fire is then lighted. The tube, C, through which the distilled products pass off to the condenser, is next connected to the cylinder by means of the adapter, B, the joint being well luted. The condenser is similar to that attached to the oven at Fig. 11, and consists of a series of pipes, I, I, I, through which C passes. Water from the pipe, L, enters the pipes, I, I, I, by means of F and the connecting pipes, *t*, *t*, near the curvature, the heated water being discharged by the pipe, *o*. The condensed products pass off into the covered receiver. The uncondensed gases are conducted through the pipe, P, back to the furnace, where they are consumed. The pipe, P, terminates in a rose, N, similar to that of a watering can, a few inches above the floor of the ashpit. The gases are by this means regularly distributed through the fire. M is a stopcock, by which the quantity of gas entering the furnace is controlled.

In some factories different methods of condensing the products are adopted. In a few instances cold air instead of water is the medium by which the vapours are condensed. The evolved products of the distillation are in this case caused to traverse an extensive range of piping of large diameter, or are conducted through a series of casks which have been connected together by pipes. Water is, however, by far the most effectual mode of condensation, and is therefore generally employed. About twenty-four hours are usually allowed to work off each batch of wood.

Schwartz' carbonizer is shown in Figs. 13, 14, and 15. Fig. 13 is a bird-eye view of the furnace, Fig. 14 a section of the elevation following the lines *d d*, and Fig. 15 another section, following the lines C C. In each of these figures similar letters are used to distinguish the same objects. A A is the space where the wood is carbonized; *b b b b* are the apertures through which the wood is introduced and the charcoal afterwards is withdrawn; C C are the fires which heat the furnace; *d d*, the openings through which the acetic acid and the smoke, carbonic acid, oleaginous, tarry matters, &c., pass off through the pipes, *g g*, and thence through the condenser into the chimney; *e e* are crooked pipes descending from *g g*, which convey the tar condensed in *g* into the vessels, *f f* (Fig. 14); the bend in the pipes, *e e*, is made in order to prevent access of air into the apparatus; H H H H are wooden canals, wherein the acetic acid and volatile oils condense; I is the chimney, and *k* a small opening in the chimney, in which a fire is occasionally lighted to establish a draught. The furnace walls are of fire-brick, or they may be made hollow, the inside layer being fire-brick, and the intervening space being filled with aluminous earth and sand.

The furnace is first charged with the heaviest blocks of wood; between these smaller wood is then introduced, for the purpose of making the interior more permeable to the action of the fire. All the orifices of the furnace are then closed, and the fires at C C lighted, the current of air being instituted in I, as above stated. The blaze of the fire traverses the furnace and carbonizes the charge of wood, and the smoke and other vapours from the furnace pass by the exit pipes, *d d*, into *g g*, whence they escape into the condensers, H H, and thence to the chimney, I. The charge is known to be completely carbonized when the smoke issuing at I, which is at first black and heavy, becomes bluish and light. The chimney passage is then closed, and the opening of the pipes, *d d*, stopped up with wooden plugs, and then well luted with some plastic clay; the fire-doors are closed and the furnace left to cool. At the end of the second day two holes in the top of the furnace, which had hitherto been closed air-tight, are opened, and water introduced to extinguish the red-hot charcoal; the openings are again closed for a longer period, and when the furnace gets a little colder more water is added. So long as any red sparks are observed, the opening and pipes must be kept carefully stopped up, since the formation of a current of air would occasion the combustion of the charcoal, and consequently lessen its produce. After complete cooling the charcoal is raked out through the apertures, *b b*, and another charge introduced. The principle of carbonization in these kinds of furnaces is different from that in those already mentioned, inasmuch as in those first described the blaze from the fire never comes in contact with the wood, while in Schwartz' furnace the blaze penetrates the entire furnace. The wood is carbonized with great rapidity by this arrangement. Another advantage which this furnace possesses is, that small wood may be burnt in C C; the acid and other valuable products being likewise collected in the condensers, H H. That which particularly distinguishes Schwartz' furnace from that of Lachabeaussière is that no air can enter it except through the fires, C C, and that there is no loss from the combustion of charcoal. The cost of this furnace is about £120, the capacity being nearly 6000 cubic feet. The successful working of Schwartz' furnace depends entirely on the exclusion of oxygen from the charcoal, a sufficient supply only being admitted to carbonize the wood.

Fig. 13.

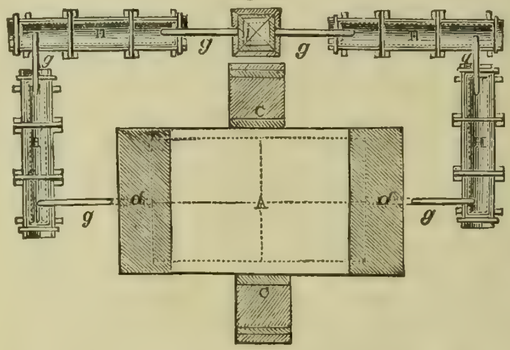


Fig. 14.

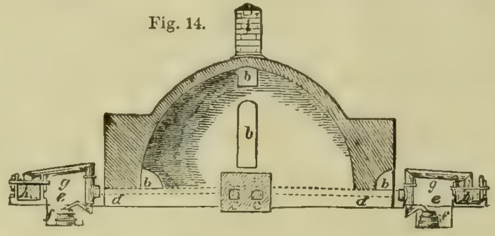
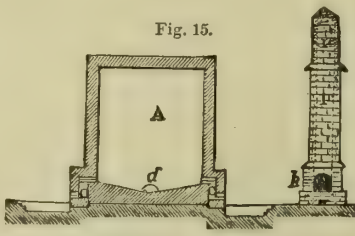


Fig. 15.



Reichenbach's carbonizing furnace consists of a square oven, the interior lining (represented in Fig. 16) of which is composed of firebrick and the outer case of any ordinary material. This oven is heated by means of tubes which traverse from one end of the case to the other, and are seen in *a b c d*, *m n o p*, in the figure; these tubes are from 1 to 2 feet in diameter. Heat is applied by lighting a fire in the tubes at *p* and *a*. When the temperature is raised so high as to cause the tubes to glow, the wood in the surrounding spaces of the oven abstracts the heat, and is thereby carbonized, the volatile products passing off at the bottom of the oven, through the opening at *x*, into the canal, *f g h*, and through that at *y* on the opposite side, into a similar canal. Both currents meet in the canal, *k i*, where the tar is partly deposited. From the tube, *k i*, the acetic vapours are carried off to the condenser, as in the ordinary process of the manufacture.

In England the retorts commonly employed are cylinders from 6 to 10 feet in length, and from 2½ to 4 feet in breadth. These are placed horizontally in brick-work domes. Their front and back ends are closed by doors which swing on stout hinges, or by plates screwed firmly to these openings. A pipe issuing near the extremity of the further end of the retort carries off the gases and condensable products to the refrigerator. A general view of the retorts and condenser is seen in Figs. 17 to 22. Fig. 17 shows the position of the cylinders when inclosed in brick-work, with the doors, K, closed. Fig. 18 represents a section of the cylinders, A, B, and C; the fire is at D, and the space, *e e*, shows the course which the flue takes round the cylinders till it reaches the chimney, E. The passage of this flue is more clearly seen in the plan, Fig. 20, where the dotted lines, *d d*, mark the circuits it makes. The space, A, B, and C (Fig. 20), indicates the cylinders and the pipes attached to them for conducting the distilled products to the tank, D, where most of the tar is deposited. From the tank, D, the product is conveyed through a small pipe into a condensing tube. This is more conspicuously seen in the elevation of the cylinder and tank, as shown in Fig. 21. Fig. 22 represents the section of a similar tank. The tank is protected by a cover, which fits into the enlarged part or groove at the top of the sides of the tank, acting as a water lute, as is seen at *h*. The pipe, *i*, carries off the acetic acid vapours to *k*, where they enter a serpentine pipe or worm in the large tub, C. A tub, *n*, is placed beneath the tank, A, to which it is connected by the tube, *m*, which penetrates through the bottom of the tank. The tarry matter, as it accumulates in the tank, falls through the pipe, *m*, into the tub, *n*. F is a tub placed below the condenser, C, where the acid is collected. The uncondensed gases pass off through the pipe, D, and are either consumed at *l*, so as not to corrupt the air in the factory, or are carried to the furnace. The arc, B, Fig. 22, shows the position of the condensing vessel with regard to the cylinders, it being the same as F in Fig. 18. The space at H (Fig. 18) may be used as a drying chamber when preparing acetates. Sometimes two of these cylinders, placed in the same dome of brickwork, are heated by one fire, the flue playing round each, as in Fig. 23, where *a a* are the cylinders, *f f f* the fires, *c c c* ash-pits, and *o o o* the course of the flue to the chimney. As many as five such carbonizers are in some chemical works placed in one arch and heated by two fires. The cylinders vary in size in different works. In some works they are 9 feet long and 2 feet 10 inches in diameter. Thirteen of these are capable of holding 5½ *cords* of wood. Each cord is 16 feet 8 inches in length, and 2 feet 2 inches in breadth, and the same in depth, its weight being, according to the state of freshness or otherwise of the wood, between 23 and 25 cwts.: 1½ ton of coal serve to carbonize the whole. The usual time occupied by the carbonization of each charge is twenty-four hours. In other works the cast-iron cylinders are 6 feet long by 4 feet in diameter, each being capable of holding about 2 tons of wood, or ¾ths of a cord. The shape of the retort is not of much importance. Wrought-iron chests are found to be very effective; they are generally provided with an iron pipe 6 inches diameter, which passes up through the centre of the chest in order to convey the heat to the interior. Each chest is made to hold 1¼ cord of wood—160 cubic feet, a cord

Fig. 16.

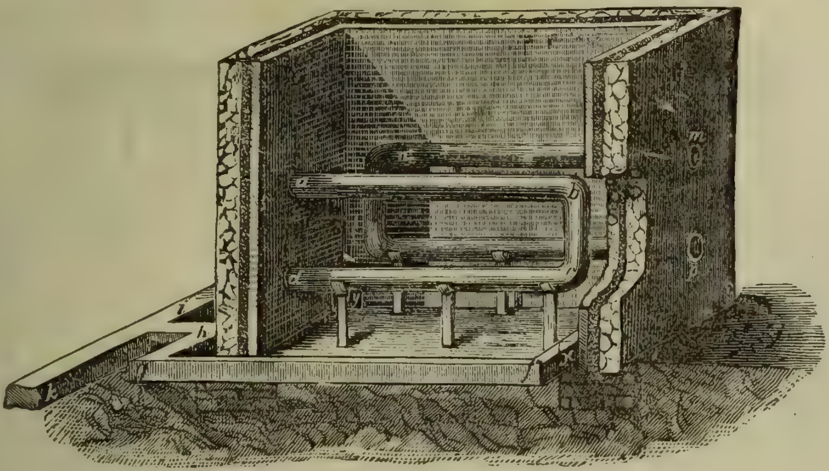


Fig. 17.

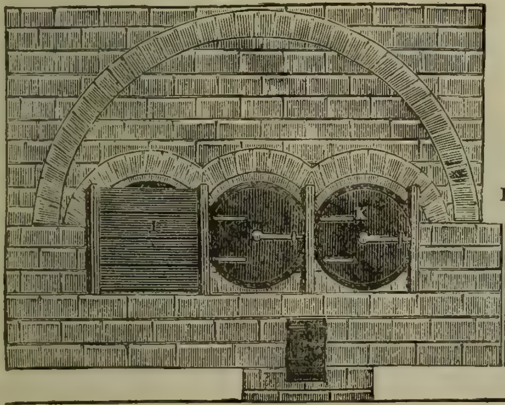
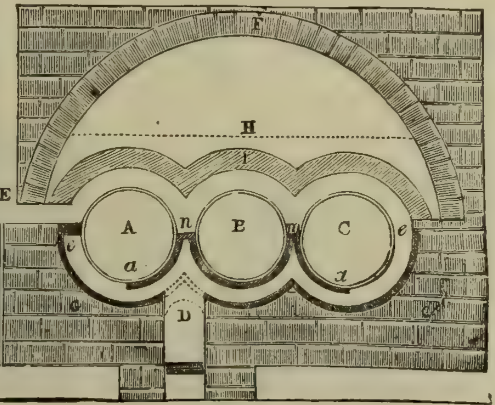


Fig. 18.

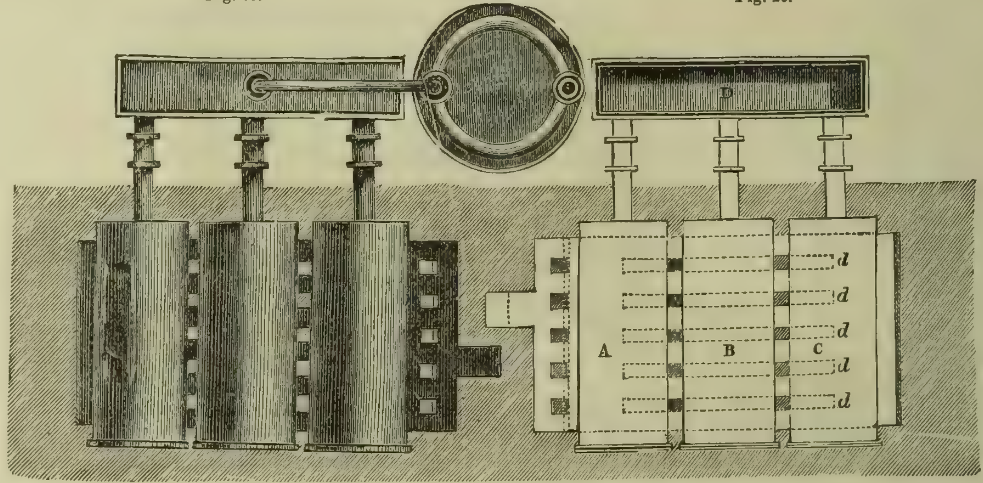


of wood being 128 cubic feet—which weighs about 3½ tons. Smaller boxes holding 1 cord of wood—their capacity being 108 cubic feet—are likewise used as carbonizers. Twenty-four hours is the time usually allowed to work off each charge; but if the demand for the distilled products be urgent the charge can be exhausted in sixteen to eighteen hours. In this case the products are less in amount than when the distillation is carried on slowly.

At works near Manchester the cast-iron cylinders are 6 feet long by 3 feet diameter, with square doors which hang on stout hinges. Generally 6 tons of wood are carbonized by 1½ ton of coal, one fire being made to heat two such cylinders, placed adjacent to each other in the same arch.

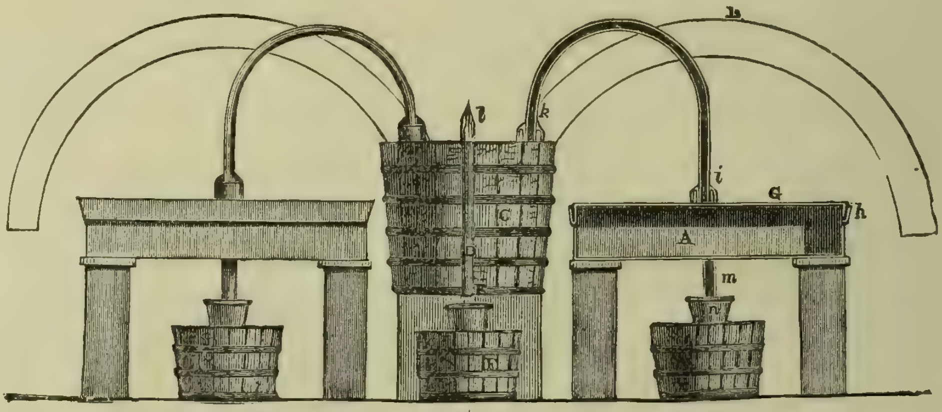
In the forest of Dean large square ovens are built, each of which contains two sheet-iron boxes, 4 feet 6 inches by 2 feet 9 inches in interior measurement. In each of these boxes about half a cord of wood is placed, and as the wood is piled up above the top of the sheet-iron box, the ovens are required to be of a size proportioned to this height. The doors of the ovens are on hinges, which are fastened and luted, when the charges are inclosed in the usual manner. These ovens are charged once a day; and as the wood is light twenty-four hours are more than sufficient to effect its carbonization. The boxes, when charged, are run into the ovens along a railroad, and are withdrawn in the same manner, whereby much labour is saved.

Fig. 19. Fig. 20.



At Swansea they use a peculiar sort of apparatus—a large sheet-iron carbonizer, cylindrical in shape, and divided internally into six compartments, into which six sheet-iron vessels, 4 feet in height and 2 feet broad, fit. In the top of the carbonizer there is but one opening through which to introduce the vessels containing the wood; but in the bottom of the outer vessel there is a movable framework, by means of which each compartment is brought directly under the opening in the top of the carbonizer, and the charged box lowered into it by a crane. When the apparatus is fully charged the opening is closed by a sheet-iron door, which is bolted and then luted in the ordinary way, after which heat is applied. The sheet-iron case is imbedded in brickwork, and the fire placed directly

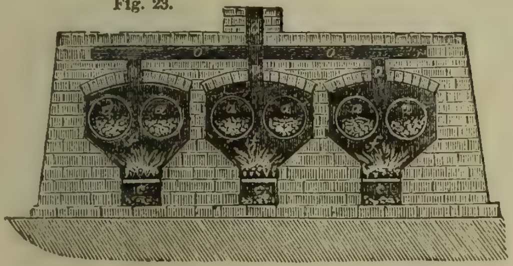
Fig. 21. Fig. 22.



under it, the flue rising spirally about the carbonizer. An apparatus similar to this is in use at Deptford.

It has been found that cylinders are the best ovens for the distillation of large billets, such as the heavy cord wood of Gloucestershire and the refuse ship-timber of Glasgow, Newcastle, and Liverpool—the most economical carbonizers being cylinders between 8 and 10 feet in length, and from 2½ to 3 feet in diameter.

Fig. 23.



Where light wood is used, such as that generally carbonized in the Welsh factories, the square ovens suit better; however, as the supply of wood is always subject to variation as to its bulk, it is frequently the practice to have both forms of apparatus.

The charcoal is at the end of the operation raked into sheet-iron boxes, or square pits sunk in the floor and lined with firebrick; both chests and pits are fitted with close-fitting covers, since, if air is not excluded, the charcoal, from its power of condensing gases in its pores, becomes so much heated as to take fire spontaneously. By shutting the charcoal in, the absorption is so far retarded as to keep the heat below the point necessary for ignition.

In many factories the charcoal is abstracted from the carbonizing cylinders by means of the following apparatus:—An iron diaphragm, almost the size of the interior of the cylinder, is placed near the mouth of the retort, having a chain attached to it which runs through the whole length of the carbonizer. The workman, by seizing this chain with a suitable instrument, draws out nearly the whole of the charcoal at once, and with less risk of breaking it than when rakes are employed.

The relative amount of charcoal, as well as of the gaseous and liquid products, depends on the species of wood subjected to distillation, and also upon the regulation of the heat by which it is effected. The temperature should at first be gentle, then gradually increase in proportion to the time, till towards the end it approaches an incipient red heat, in order to dissipate the whole of the volatile products of the wood. The strongest acetic acid is generally obtained from timber of slow growth on dry soils, the next quality from timber grown on moist ground, and the weakest, and that which contains most empyreumatic oils, &c., from pines and resinous trees. The produce of the last-mentioned variety is not, however, so inferior as is generally stated, when proper attention is paid to the regulation of the temperature and complete carbonization of the charges.

In establishing a chemical works for the distillation of wood, the first points to be considered are the supply of wood and the means of disposing of the charcoal. Charcoal is bulky, and deteriorates very rapidly in transit, and as a rule has a rather high tariff fixed upon it by railway companies. An abundant supply of water is also essential.

In this country the woods used for distilling are oak, beech, birch, thorn, crab, or apple, and exceptionally hazel, alder, ash, and maple. It is only under very special circumstances that coniferous woods are distilled. Holly and yew are highly esteemed when they can be obtained, but are not sufficiently common to be much used.

Of all these the oak is, according to both E. T. Chapman and Watson Smith, that which is most generally sought after, oak crop wood and old oak timber being the forms in which it is most readily obtainable; birch and beech follow next in order of superiority. The oak crop employed is almost invariably either the "lop"—that is, the lesser branches of large trees—or the saplings specially grown for their bark. In any case the greater part of the bark is removed before the wood is sold to the distiller. This "peeled oak," as it is called, would probably be used to the exclusion of every other wood, could it be obtained in sufficient quantity and at the same price as other woods; the only objection to it being that its charcoal is brittle, and therefore, in wood distiller's phrase, does not measure well. Charcoal *buyers* make no objection to it.

Beech is reported to be a particularly useful wood. It is the only wood employed in England in the form of large trees. Such timber is first sawn into convenient lengths for the oven, holes are then drilled in the logs, sometimes in the end, sometimes in the side, a charge of gunpowder introduced, and the log blasted to form suitable fragments. Beech wood furnishes much tar, gives a large yield of naphtha, and is said to be the best source of creosote; its charcoal is also good.

For the preparation of pure acetic acid, or a pure acetate, birch is beyond all doubt one of the very best woods, thorn and apple being nearly its equal. It is, however, by no means always the object of the distiller to prepare a particularly pure acetate; he generally takes into consideration the amount of yield of other profitable products.

Coppice wood, generally consisting of a mixture of hazel, alder, ash, and maple, together with smaller quantities of birch, beech, and oak, are very extensively used. These woods vary in value according to their size; they are most esteemed when of from fourteen to eighteen years' growth. In this country they are generally cut much too early, sometimes at the end of six years. According to German experience, the greatest yield of wood is not attained till much later.

Roots of trees are occasionally distilled, provided they are not decayed. They are broken up into moderately sized pieces, and generally furnish a very valuable distillate and leave good charcoal. The chief objection to them is the great labour required in breaking them up. They are sometimes put in the oven whole and heated for forty-eight hours.

As a general rule, hardly liable to exception, the larger the wood the better is it suited for distilling purposes, provided it can be completely charred in the twenty-two hours or so during which it is in the ovens.

Decayed woods of all kinds are to be avoided if possible, especially large logs of which a portion is decayed, as the charcoal from them generally proves to be spontaneously combustible. Holly wood also yields a charcoal which is very liable to spontaneous combustion.

The following is a tabular view, arranged by **Stolze**, of the amount and strength of the products obtained from the distillation of several varieties of wood. The quantity of each kind of wood submitted to destructive distillation was *one pound*, a quantity suitable, in the generality of cases, to form a precedent for the manufacturer on the large scale:—

One Pound of Wood.		Weight of Acid.	One ounce of Acid neutralized of pure Carbonate of Potassa.	Weight of Empyreumatic Oil.	Weight of Charcoal.
	Botanical Names.	Ounces.	Grains.	Ounces.	Ounces.
White Birch	Betula Alba	7⅛	55	1⅜	3⅞
Red Beech	Fagus Sylvatica	7	54	1¼	3⅞
Large-leaved Linden	Tilia Plataphylla	6⅞	52	1⅞	3⅝
Oak	Quercus Robur	6⅛	50	1¼	4⅛
Common Ash	Fraxinus Excelsior	7¼	44	1⅜	3¾
Horse Chestnut	Esculus Hippocastanum	7⅜	41	1⅜	3½
Lombardy Poplar	Populus Dilatata	7⅜	40	1⅜	3¾
White Poplar	Populus Alba—abele	7⅜	39	1¼	3¾
Bird Cherry	Prunus Padus	7	37	1¼	3½
Basket Willow	Salix	7⅜	35	1¼	3½
Buckthorn	Rhamnus	7⅛	34	1⅜	3½
Logwood	Hematoxylon Campechianum	7⅛	35	1½	2
Alder	Alnus	7¾	30	1½	3½
Juniper	Juniperus Communis	7¼	29	1¾	3⅝
White Fir	Pinus Abies	6⅜	29	2⅛	3⅜
Common Pine	Pinus Sylvestris	6¼	28	1⅞	3½
Common Savine	Juniperus Sabina	7	27	1⅞	3⅝
Red Fir	Abies Pectinata	6⅜	25	2¼	3¾

Eighty-four Pounds of Wood.	Charcoal.	Charcoal per cwt. of Wood.	Acid liquor.	Sp. gr. of Acid liquor.	Sp. gr. of Acid liquor saturated with Lime.	Measures of Soda to neutralize Acid liquor.	Incondensable products.	Real Acid.
Birch,	23½	31·33	45	1·046	1·080	70	15	1·86
Elm,	21½	28·66	45½	1·036	1·075	83	17½	2·26
Willow,	18	24·00	49	1·029	1·045	29	17	0·77
Beech, low temp.	24	32·00	46	1·039	1·090	115	14	3·06
Do. high temp.	20	26·64	47	1·034	1·067	90	17	2·40
Laburnum,	20	26·64	46	1·030	1·055	75	18	2·00
Ash,	23	30·68	48	1·035	1·078	92	13	2·45
Alder,	20	26·64	48	1·030	1·065	70	16	1·86
Hawthorn,	20	26·64	27	1·040	1 100	140	37	3·73
Young Oak,	28	37·33	39	1·038	1·085	115	14	3 06

Three hundred and thirty-six Pounds of Wood.	Charcoal.	Charcoal per cwt. of Wood.	Acid liquor.	Sp. gr. of Acid liquor.	One ounce neutralized grs. of Bicarbonate of Potassa.	Dry Acetate of Lime produced.
Beech,	84	28·00	180	1·029	9½	25
Walnut	72	24·00	150	1·018	7	14½
Birch, cut three years	70	23·33	120	1·031	11	13
Oak,	91	30·33	190	1·022	8	24
Ash,	90	30·00	190	1·024	8	22
Apple,	70	23·33	200	1·017	6	18
Wych Elm,	70	23·33	180	1·018	8	16
Maple,	77	25·66	145	1 018	6	20

The average production of three works in the neighbourhood of Paris, from 4000 lbs. of wood, beech and oak, was:—

Charcoal, ... 1,014 lbs.
Acid Liquor, ... 2,335 " sp. gr. 1·027 = 416 lbs. of dry acetate of lime.
Tar, ... 330 "

The following were the amounts obtained at the works of M. **Mollerat**, at Nuits, from 1000 stères of wood, weighing 5120 cwts.:—

Charcoal,	1,280 cwts.
Pyroligneous acid,	850 "
Acetic acid,	54 "
Acetate of lead,	152 "

In a well-conducted establishment in England the annexed were the quantities of crude acid liquor obtained by the distillation of 1634 cords of wood (each cord of wood weighing 512 cwts.), according to the longer or shorter time allowed to intervene between the cutting and the using of the wood:—

174 cords produced 23,923 gallons of about 10 lbs. each.
160 .. .. 27,720 .. .. ..
252 .. .. 30,424 .. .. ..
318 .. .. 40,584 .. .. ..
330 .. .. 55 900 .. .. ..
400 .. .. 50,700 .. .. ..

Watson Smith states that, according to his experience, the average yield which has been obtained, when old oak timber has been used in the retorts, after being split up and sawn into pieces of from 2 to 2½ inches long and 3 to 4 inches thick, was:—

Wood	Charcoal.	Wood Acid.	Tar.
From 1000 parts by weight,	327	509	55

The wood acid had a specific gravity of from 1·025 to 1·027 (= 5½° T.). In order to carbonize a ton of wood 10½ cwts. of coal were used on the average. He considers that the amount for fuel stated above, namely, 7 cwts. per ton of wood, can only be secured by the greatest economy and the most efficient flue and draught arrangements, so that the heat could be utilized to the uttermost.

The subjoined is one of the monthly statements of works in the vicinity of Paris, in which the wood is carbonized by utilizing the heat from ovens for the manufacture of coke.

Dr.	Frs.	C.
1000 Hectolitres of coal, at 50 frs. the 15 hecto.,	3,333	33
500 Stères, halfcords, of wood, at 9fr. 20 c.,	4,600	00
Wages of coke-oven man,	120	00
Wages of six workmen,	450	00
Wages and lodging of two carmen,	200	00
Keep of two horses..	180	00
Salary of director of works,	200	00
Wear and tear, calculated at 10 per cent. on the value of the plant—60,000 frs.	500	00
5 per cent. interest on capital,	416	00
Rent of ground and cellars for charcoal,	100	00
Frs.	10,099	33

Cr.	Frs.	C.
1320 Hectolitres of coke, at 49 fr. the 15 hecto.,	4,312	00
450 Hectolitres small coke, at 32 fr. 50 c. the 15 hecto,	975	00
750 Loads of charcoal, at 6 fr.,	4,500	00
150 do., second quality, 5 fr.,	750	00
50 do., third quality, 4 fr.,	200	00
20 do., powder, 2 fr. 50 c.,	62	50
200 casks pyroligneous acid, at 15 fr.,	3,000	00
Tar,	165	00
Frs.	13,964	50

One franc equals 10*d*. English; 100 centimes are equivalent to a franc. The French hectolitre is a measure of capacity, containing 100 litres, equal 22·009668 imperial gallons; 4·5434579 litres equal an imperial gallon.

The temperature at which wood is distilled makes, according to CHAPMAN, a marked difference in the nature of the products obtained from it. In a series of experiments made on oak sawdust, he obtained from 13 to 27 per cent. of the sawdust in the form of charcoal, simply by varying the temperature at which the charring was effected. The higher the temperature the smaller the yield of charcoal. When, however, the heat was very gradually increased, so that the charring was effected at a low temperature, the yield was invariably only slightly less than it was when the wood had been charred at a permanently low temperature; so that the large yield in the case of the low temperature was not due to imperfect charring.

When the wood is very rapidly charred the amount of liquid which distils from it is always less than when it is charred slowly, and the amount of uncondensable gas is very greatly larger. The amount of acetic acid is also larger at a low than at a high temperature. It is generally admitted that the largest amount of acetic acid is obtained with large ovens at a low temperature. On the other hand, when naphtha is desired, it is believed that small ovens very highly heated give the greatest yield; though the large quantity of permanent gas generated must carry off with it much of the volatile spirit.

It is still a disputed point amongst distillers as to whether wrought or cast iron is the better material for the ovens. According to the experience of one manufacturer wrought-iron ovens will hardly last thirty charges; according to another they will last five to six years. CHAPMAN considers that when properly protected by brickwork, and with careful firing, wrought iron is quite equal to cast iron in point of endurance. It is, of course, much less liable to crack, and may be made very much thinner, therefore wasting less fuel. Its disadvantages are, that vessels made of it easily lose their shape by overheating, and are somewhat apt to leak at the joints. Wrought-iron ovens are always furnished with cast-iron exit pipes and doors, as wrought iron is rapidly attacked by the acid vapours, unless it is sufficiently hot to prevent any condensation upon its surface. Wrought iron is only employed for the construction of cylindrical retorts.

Cast iron is most commonly employed. Its advantages are obvious; the whole oven may be, and frequently is, cast in one piece, so that there is no chance of leakage from it. Its disadvantages are, that it is apt to crack with the fire, and when cracked it is difficult to repair it satisfactorily; this is especially the case with cylindrical ovens cast in one piece. Square ovens are frequently built up of plates of cast iron bolted together.

The following are the dimensions of various ovens in actual use:—

	Description of Oven.		Length.	Diameter.	Depth.	Breadth.	Area.
			Feet.	Feet.	Feet.	Feet.	Cubic Feet.
1	Wrought iron,	cylindrical,	7·0	5·0	—	—	137·50
2	“	“	9·5	3·5	—	—	91·39
3	Cast iron,	“	10·0	3·5	—	—	96·00
4	“	“	10·0	3·1	—	—	115·40
5	“	“	4·5	3·0	—	—	31·77
6	“	“	7·0	2·5	—	—	34·30
7	“	rectangular,	7·0	—	4·50	3·66	115·29
8	“	“	9·5	—	5·00	3·66	174·00
9	“	“	10·0	—	4·33	4·33	187·76

Of these ovens, Nos. 1, 3, and 4 have been reported upon very favourably. No. 5 is an old pattern, not likely to be ever again constructed, though still in use. No. 6 is used to prepare special kinds of charcoal, and in some works to burn heavy timber from ship breakers' yards. No. 7 is not an approved pattern. No. 8 is considered to be a very good oven; some ovens constructed on the same pattern have been in use for twenty years. No. 9 is the largest square oven which has been built.

Whatever the form of oven employed, it must be properly protected with brickwork from the direct action of the fire. No. 1 is protected for two-thirds of its circumference; one fire heats two of these ovens. No. 2 is similarly protected, but each oven has an independent fire. Nos. 3 and 4 are only protected at the bottom; they have a separate fire to each, though occasionally two ovens of the dimensions of No. 4 are heated by one fire. Nos. 5 and 6 have each a separate fire.

All the rectangular ovens have a separate furnace. As a rule, they are protected with brickwork as to their bottom plates only.

The composition of the permanent gas passing through the condensers, and which in this country is almost invariably allowed to escape, varies very greatly with the time that the wood has been in the oven and with the heat employed. If a sample of it be collected soon after the decomposition of the wood has commenced, it will be found to be colourless, have scarcely any perceptible smell, and to burn with a blue flame. It consists of a mixture of carbonic acid, hydrogen, and marsh gas.

As the temperature rises, the escaping gas becomes clouded with a tarry smoke; it now burns with a yellow smoky flame. If a sample of it be collected and allowed to stand for two or three days in a bottle, it deposits tar and becomes colourless; and if the temperature of the ovens has been kept very low it burns with a yellow, slightly luminous flame. It contains carbonic acid and gases absorbable by bromine. After these have been removed, the gas burns with a blue flame like that of alcohol, and consists of a mixture of carbonic oxide and hydrocarbon gases.

Towards the end of the operation the gases are richer in illuminating power, derived from gases not absorbable by bromine. Even right up to the end of the operation, however, the gas when purified by long standing, treatment with bromine, washing with alcohol, and then with aqueous potash, has very little illuminating power. It does not appear, therefore, that any hydrocarbons of the marsh gas series of at all complex formulæ are produced. Carbonic oxide increases in quantity as the distillation progresses; and at the end of the process, especially if the temperature be allowed to rise rather high, its quantity is very considerable.

The illuminating power of the gas, after standing and washing in alcohol, is greatest somewhat before the close of the distillation. If the temperature be kept low in the ovens, the illuminating power in the washed gas is never high. Of course the gas is charged with volatile liquids produced during the distillation, and therefore has considerable illuminating power as it leaves the condensers. The condensation should be so complete that no patch of condensed fluid is formed in the hand when the palm is held before the jet of escaping gas.

The termination of the distilling process is ascertained by handling the exit pipe from any of the retorts into the main; when this is found to have cooled down the distillation has ceased. The fire is then drawn, and the retort allowed to stand till the following morning to get cool. When the doors are opened the charcoal is raked out as rapidly as possible into capacious iron barrows, which when full are wheeled to the trap door, or man-hole of one of the underground strong tanks or vaults. The barrow with its load of still partially-ignited charcoal is upset over the open trap door, and the charcoal rapidly shovelled into the vault. When the charcoal from all the retorts requiring to be emptied has been collected in the vault, a few buckets of water are thrown in upon it, and the trap door is then securely luted down.

The mixture of tar and crude wood acid which came over into the condensers is then pumped into a large cistern at a convenient height above the ground and allowed to settle. The tar, of course, forms the lower, and the crude acetic acid the upper layer of fluid. When required, the tar is drawn off by a tap at the bottom, and the acetic acid liquor by a tap, or siphon arrangement.

Some years ago a patent was taken out by A. P. HALLIDAY, of Salford, for the manufacture of pyroligneous acid, &c., from sawdust, spent bark from tanyards, and dyewoods exhausted of their colouring matters. His process proved very successful, and was adopted by the largest and most eminent manufacturers of decoctions in this kingdom. Ultimately the process was also carried on as an independent manufacture on a large scale.

The distillation of sawdust had for a long time previous been attempted, but without success. Ordinary ovens and retorts proved to be quite unfit for the decomposition of sawdust by heat. It was found that almost immediately heat was applied to retorts containing sawdust, it became coated with a close, hard layer of carbon, which, being a non-conductor, effectually barred the heat from penetrating to the interior of the mass, no matter how high the temperature to which it was exposed.

HALLIDAY set himself the task of overcoming this difficulty, and Fig. 24 is a drawing of the ingenious apparatus which he devised for this purpose, and by which this obstacle was effectually overcome. The sawdust, spent dyewood, &c., are introduced into a hopper, H, placed above the front end of an ordinary cylinder, A A, in which a vertical screw or worm, C, revolves at such a speed as to convey the material in the proper quantities to the cylinder, which is placed in a horizontal position, and heated by means of a furnace, F. Another revolving screw or worm, B B, keeps the sawdust or other wood powder, introduced into the retort by C, in constant motion, and at the same time moves it forward to the opposite end of the retort. During their progress through the retort the materials are completely carbonized, and all the volatile products disengaged. Two pipes branch off from the extremity of the retort, one of which, D, passes downwards and dips into an air-tight vessel of cast iron, or a cistern of water, E, into which the carbonized substance falls; the other is an ascending pipe, K, and carries off the volatile products of the distillation into the condenser, which consists of copper or iron pipes immersed in or surrounded by water. The charcoal obtained, when ground finely, answers well for steel manufacturers and iron founders.

The quantity of acid obtained from spent dyewoods usually equals the amount obtained in the ordinary distillation of wood. It is, moreover, stated by HALLIDAY, and also by HADFIELD, that when burnt as sawdust in these retorts, the yield of acetic acid from pine and other resinous woods is very considerable. In ordinary ovens, as before remarked, these woods yield very little acid as compared with oak, beech, &c. It is also averred that in practical working eight retorts of the above description, 14 inches diameter, produce as much pyroligneous acid in twenty-four hours as sixteen retorts, 3 feet in diameter, worked on the old system, yield during the same time.

The average produce from eight retorts, taken for many weeks, carbonizing 22 tons of sawdust weekly, is the following:—

Pyroligneous acid 10° Twaddle = 1·05,..	2484 gallons.
Tar,..................................	240 "

To which, by way of comparison, is subjoined the average yield per ton of oak, when carbonized in the ordinary cylinders.

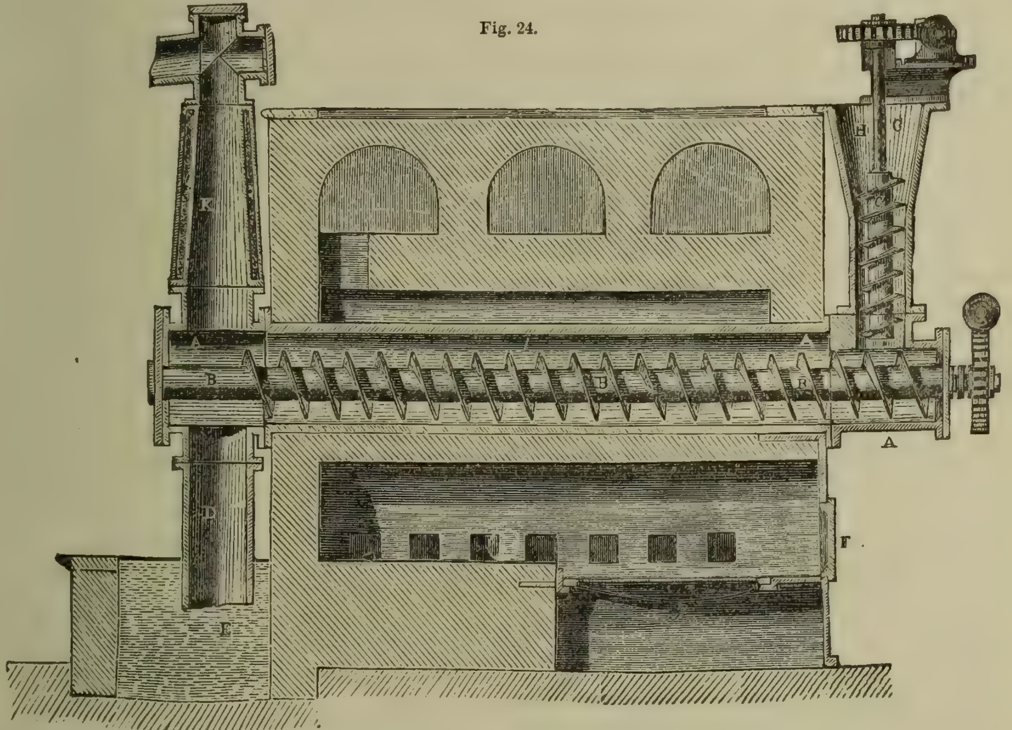
Weight of wood,.........................		2240 lbs.
" pyroligneous acid,.....	1277 lbs.	
" charcoal, ...	600 "	
	——	1877 "
Loss—uncondensable gases,.........		363 "

According to the state of dryness of the wood when submitted to the retorts, the products are a little more or less; but generally the range of produce is between 124 and 127 gallons of 6° Twaddle, or 1·03 spec. grav., and 600 pounds of charcoal. It is therefore evident that the same quantity of acid is obtained from the sawdust, and is besides of a far higher specific gravity.

The average price of oak wood is eighteen to twenty shillings per ton, and for cutting this in convenient billets for the retorts and ovens the cost is usually about two shillings to two and sixpence per ton. From 7 to 10 cwts. of coals are found sufficient to carbonize 1 ton of wood. The tar obtained in distilling pine wood sawdust is of equal quality to that imported.

In the vicinity of Manchester, where exhausted dyewoods and sawdust are plentiful, a decided advantage in the yield and quality of the products is to be gained by operating upon those materials.

Fig. 24.



Many modifications of the Halliday oven have been made, but all upon the same principle; namely, that of keeping the powdered wood constantly moving. One of the most ingenious of these is that devised by W. H. Bowers of Manchester. His apparatus consists of a long rectangular retort, set at an angle of about 25° and heated by external flues, which run along its entire length. Within this oven are four revolving drums, moved by a small steam engine, which carry an endless chain to which projecting scrapers are attached at short intervals, in order to keep the floor clear of sawdust or charcoal. At the upper part of the retort a hopper is placed, through which the sawdust, wood-turnings, spent dye-wood, tan, or other materials, are introduced. The vapours are carried off by pipes in the usual way, and the charcoal after leaving the chain falls into a cistern, which forms the lower termination of the retort. The gases are prevented from escaping into the air by the thickness of the mass of sawdust at the top of the retort and by the water-joint at the bottom. The motion and the heat can be increased or diminished at will, the scrapers obviate the necessity of stopping working for cleansing purposes; the apparatus can therefore be worked continuously from month to month. Two of these ovens, with slow motion, produce 2500 gallons weekly.

SOLOMONS and AZULAY have patented a process, the main feature in which is the transmission of steam heated to a high temperature through the mass of material. The steam pipes are so arranged that every particle of sawdust is exposed to the superheated steam, and is thus completely carbonized. The products are those ordinarily obtained in ligneous distillation. The steam accompanying the distillates renders them dilute; this drawback is, however, compensated to a great extent by causing the mixed steam and volatile products to traverse a coil of piping placed in a pan of the distillates, from which the pyroligneous acid and other products pass to the main condenser. If this had not been suggested by a chemist, the patent could never have been profitably worked. The heated steam prevents the deposit of tarry and other resinous matters; consequently, no choking of the pipe need be apprehended.

The following brief sketch of the pyroligneous acid manufacture was contributed by JOHN RANDALL, manager of the Pitchcoombe Works at Stroud, to the last edition of this dictionary:—

"It remains still a disputed point whether small or large retorts are preferable. After a trial of different sizes, and some years' experience, the writer considers a retort of moderate dimensions the most convenient and serviceable. Those in use here are 9½ feet in length and 2½ feet in diameter, inclosed in brickwork, and placed horizontally, three or five in a set.

"They are secured in front by lids, fastened by means of a cross bar. At the back there is an exit pipe, 8 inches in diameter, connected with a main pipe. From this the liquor is conducted by a series of pipes, immersed in water, into a large tank. Retorts set in the method described are heated more economically, and the charcoal is good.

"Each retort holds about half a cord of wood, which, when of beech of the average dryness, weighs about 12 cwts. These retorts are charged once in twenty-four hours. As to the quantity of liquor produced from a given weight of wood, of course much depends on the condition of the wood, whether green or dry—that which has been cut down about six months is the best for practical purposes, the liquor being stronger in acid. A cord of wood in this state yields from 120 to 130 gallons of liquor, consisting of pyroligneous acid, water, naphtha, and tar, leaving charcoal in the retort equal in amount to about one-fifth of the weight of the wood originally employed. The next process is to separate these various products, and for this purpose the liquor is pumped up into copper stills, heated for safety by steam. Naphtha, in a weak and impure state, comes over first, then the pyroligneous acid, leaving a tarry residuum in the retort. Some manufacturers prefer adding lime to the liquor in the tank before it is transferred to the stills: this is, perhaps, best for the production of naphtha, but it involves the necessity of making black or brown acetate of lime, which from its inferior quality is often difficult of sale, except at a low price.

"After distillation the acid is removed to large tubs or vats, and neutralized with lime. It is then allowed to stand for a few hours, and the clear solution siphoned off into evaporating pans. The vessels used here for this purpose are made of wrought iron, are oblong in shape, about 9 feet in length, 4 feet in width, and 2 feet in depth; they contain about 450 gallons. The solution is boiled down to the desired consistency, put into draining buckets, and then removed to a drying stove. This is the ordinary process; but when the acetate is required of superior quality, the solution is properly evaporated, then allowed to stand for eight or ten hours, carefully drained off from its sediment, and boiled to its crystallizing point. Simple distillation, though it separates a large portion of tarry matter, never renders the pyroligneous acid pure; this can only be effected by neutralizing the acid with carbonate of soda, evaporating the solution to dryness, and then subjecting the mass to fusion. The resulting *black cake*, as it is termed, is redissolved, boiled to a crystallizing point, and drawn out into large shallow vessels to deposit the salt."

Some time back PAUER discovered a method for the preparation of acetic acid and acetates from the distillation of wood, in which he dispensed with distillation, evaporation, and the greater part of the heating required in the processes generally pursued in this branch of the manufacture.

His method consisted in presenting to the acetic acid vapour, during the carbonization of the wood, a substance which can seize exclusively upon it, and thereby concentrate it.

The bodies which will the most readily satisfy this condition are those bases whose acetates are not decomposable at the temperature of the operation; such as potassa, soda, baryta, lime, magnesia, &c., or the carbonates of these bases, or any other salt whose acid can be displaced by the acetic acid. The author gives the preference, according to locality, to lime, a calcareous carbonate, magnesian carbonate, or carbonate of soda. The first three on account of their low price; the last because it yields the acetate of soda directly—a product prepared at a future stage for the entire purification of the acid.

PAUER's process may be applied to any method of carbonization. The manner in which it is adapted to carbonization *en meules*—piles or masses of rough wood with earth—will now be described.

It is well known that carbonization *en meules* is effected by the heat produced by means of the combustion of a certain quantity of the wood of the pile when ignited. Orifices left at the foot of the pile give access to the air necessary for combustion; others pierced at different heights and in different positions by the workman charged with directing the progress of the carbonization, serve for the escape of the products of the combustion and distillation. In these last orifices, at the point where the workman has judged it necessary to carry the draught, M. PAUER introduces tubes into the earth of about one inch interior diameter and half an inch in thickness, which, dividing over all the pile, terminate in bundles in numerous suitable vessels for collecting the products which are distributed around the wood stack. These pipes may be composed of several ends or short pieces, connected by joints, so that, when the progress of the carbonization requires the displacement of the orifices for the emission of the smoke, the extremity only of the tubes need be removed, thus avoiding the necessity of deranging the receivers.

The latter are generally simple casks, of 14 inches diameter and 3¼ feet in height, which are filled, in whole or in part, with pieces of lime, carbonate of lime, or carbonate of soda, divided into fragments varying in size according to the state of porosity of the particular substance used, interstices being left between the pieces to permit the passage of the vapours.

Acetic acid, and the other products which escape from the wood, are conducted by the pipes to the bottom of the cask, and traverse the different layers of carbonates or of lime which fix the acetic acid, whilst the other products escape at the top of the receiver.

It is proper to remark that this process presents one advantage over that by refrigeration, namely, that owing to the high temperature maintained in the interior of the casks, much less tar is condensed, and the subsequent purification of the acetic acid is thus rendered more easy.

The acetate of lime obtained in this manner may be submitted to the same operations as in the processes at present in use.

It is possible, under certain circumstances, to introduce into the midst of the pile, in the intervals left between the logs, the substance intended to unite with the acetic acid. Receivers are then unnecessary.

There are some factories which distil wood in close vessels expressly to obtain the acetic acid. For these the method described would have great advantages. In fact, there would be nothing to prevent the temperature of carbonization being so regulated that the acetate of soda produced in the apparatus itself should not be decomposed, at the same time keeping the temperature sufficiently high to destroy or expel the tar; the torrefaction would thus be combined with the carbonization, so as to obtain a concentrated and purified body at one operation.

Purification of Pyroligneous Acid or Wood Vinegar.—This is effected by saturating the crude liquor remaining after the spirit has been separated with a base, evaporating to dryness and calcining the dry salt, so as to decompose the oleaginous and tarry matters present, and afterwards distilling this body with an acid—sulphuric or hydrochloric acid—and rectifying the distillate repeatedly over chloride of calcium or carbonate of soda. Lime or soda is generally employed for this purpose. After the naphtha has been expelled the acid liquor is run off from the still into the tanks, to deposit a portion of its impurities, it is next pumped into another pan, and milk of lime, or burned lime, made into a thick paste with water, added slightly in excess, and the mixture boiled for a short time, and then run off into a vessel to rest for ten or twelve hours. During this time the excess of lime, and part of the impurities combined with it, precipitate, when the supernatant liquid is ready to be pumped into the evaporating pans. If the crude acid liquor is distilled before neutralizing with lime, the distillate is saturated with lime in an appropriate cistern or vat, and when the solid matters have subsided the clear fluid is pumped into the evaporating pans. In some works the evaporators are wooden vessels, lined with lead, in which is a coil of iron piping, through which steam passes, while in others they use shallow pans of sheet iron, having a fire beneath them. In any case the liquid is frequently stirred with a large wooden spatula, and the matters which rise to the top during evaporation are carefully skimmed off. As the evaporation of the liquor advances, the acetate of lime crystallizes and forms a layer on the surface, which is collected with large scoops or ladles, and deposited in baskets, supported on a frame, placed directly over the pans, in order to prevent the cooling of the drainings.

The whole of the acetate of lime is removed in the manner above described. When the crude acid is distilled previous to saturation with lime, the acetate of lime which it produces is called *grey acetate;* if the acid be neutralized without distillation the lime salt is called *brown acetate*, sometimes *black acetate*. The acetate is then heated in a drying furnace at a temperature of 450° Fahr. (232° C.), to carbonize the resinous and other impurities. To obtain the pure acid, the grey acetate of lime is dissolved in water till the solution has a specific gravity of 1·200; it is then filtered to separate the carbon, and sulphate of soda in powder added, after which the whole is briskly agitated, to insure the complete decomposition of the lime salt. The sulphate of soda is to be added until a small portion of the liquor gives no precipitate on the addition of a concentrated solution of this salt. The quantity of crystallized sulphate of soda required to effect a complete decomposition is about four times the weight of acetate of lime operated upon; that this large amount of the decomposing body is needed is owing to the formation of a double salt of calcium and sodium, thus:—

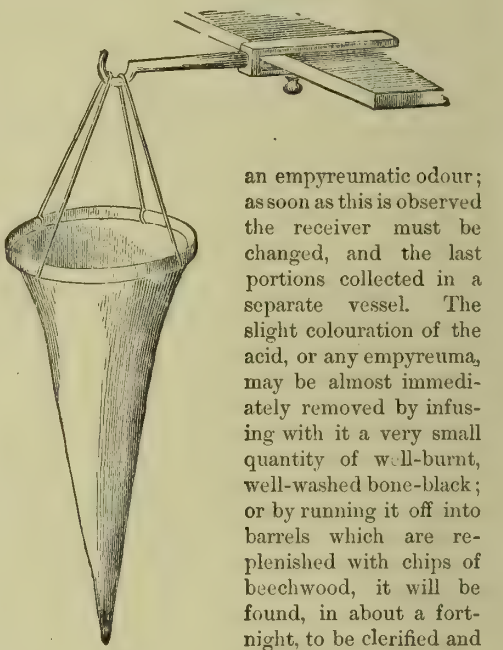
$$Ca(C_2H_3O_2)_2 + 2Na_2SO_4 = 2NaC_2H_3O_2 + CaNa_2(SO_4)_2.$$

The solution of acetate of soda, after the subsidence of the sulphate of soda and lime is drawn off and evaporated, and the precipitated sulphates are washed with water till the liquor is nearly tasteless; the washings being retained to dissolve fresh quantities of acetate of lime. The acetate of soda liquor is concentrated in pots 6 feet diameter and 3 feet deep, till it acquires a density of 1·300, care being taken to separate the impurities that rise to the top. If an excess of sulphate of soda has been used in the decomposition of the lime salt, it will now crystallize. The crystals are removed by the scoops ladles, and thrown into a wicker basket above the evaporating pans, as before mentioned, so that the drainings may flow back to the remaining liquor without losing much heat. After separating the crystallized sulphate of soda the liquor is allowed to rest for eight or ten hours, to deposit impurities that are separated during the boiling, and is afterwards drawn off to the crystallizing pans, where it remains for three to five days. The crystals are then removed, and the mother liquor again concentrated to 1·300 (the tarry matters being removed as before), is again run off to recrystallize; and so on till the mother liquor no longer yields crystals. This liquor is evaporated to dryness and the residue calcined at a red heat, when carbonate of soda is formed, which may be extracted by solution in water; or the brownish residue may be calcined at 450° Fahr., and the acetate of soda dissolved out by water. The crystals of soda acetate are dissolved in fresh quantities of water, and re-evaporated till the solution is 1·500; left to repose for ten hours, the resinous bodies separated, and recrystallized at a density of 1·50: the mother liquor is treated as above detailed.

The crystals are next fused at a temperature of 400° Fahr. (204° C.), in an iron pot, and the mass kept constantly stirred till the whole of their water of crystallization is eliminated. During this part of the operation the greatest precautions are to be observed as to the maintaining of an even temperature—never exceeding 450° Fahr. (232° C.)—and guarding against any sparks coming into contact with the fusing mass. This latter accident would destroy the whole of the compound, since it burns like tinder in contact with fire. When white fumes rise from the liquefied salt it is an indication that decomposition is taking place, in consequence of the temperature being too high. The fire doors should in this case be immediately thrown open, and the fire itself drawn if the pot be still too hot. The termination of the drying is known by the subsidence of frothing, and by the fused mass presenting the appearance of an oily liquid, at which stage it is either drawn off by a pipe issuing from the bottom of the pot, or ladled out on iron plates to cool, and, when solidified, broken up into fragments. On dissolving this compound in twice its weight of water, filtering through bags similar to Fig. 25, and crystallizing, a very pure soda acetate is obtained. For the production of acetic acid from acetate of soda, a quantity of this salt is put into a stout copper still, and a deep cavity made in the centre of the mass, into which sulphuric acid, of spec. grav. 1·84, is poured, in the proportion of 35 per cent. of the weight of the salt; the walls of the cavity are thrown in upon the acid, and the whole briskly agitated with a wooden spatula. The head of the still is then luted and connected with the condensing worm, and the distillation carried on at a very gentle heat. The worm should be of silver or porcelain, as also the still head, and even silver solder should be used to make the joints in the body of the still.

In some factories it is usual to have the lower half of the still encased in an iron jacket, which receives high pressure steam, or holds oil, tallow, or other media for storing up heat: when steam is used the under part of the iron jacket should be furnished with a stopcock, to allow the condensed water to flow off; and where oil or tallow is the medium that gives heat to the boiler, a safety tube should be fitted to it to carry off the gases which would be produced if the temperature should happen to be too high. The iron jacket is placed directly over the fire when steam is not used. Towards the end of the distillation the acid passing over acquires an empyreumatic odour; as soon as this is observed the receiver must be changed, and the last portions collected in a separate vessel. The slight colouration of the acid, or any empyreuma, may be almost immediately removed by infusing with it a very small quantity of well-burnt, well-washed bone-black; or by running it off into barrels which are replenished with chips of beechwood, it will be found, in about a fortnight, to be clerified and ready for sale.

Fig. 25.



The acid which runs over is colourless, and contains about 45 per cent. of anhydrous acetic acid, its specific gravity being 1·05. Strong acid is procured by distilling the preceding acid, of specific gravity 1·05, with fused chloride of calcium, and receiving the distillate in a refrigerator; part of the acid which passes over crystallizes: the crystals are removed and dissolved in their own water, and subjected to a second rectification as before: this is continued till the whole of the acid crystallizes at 55° Fahr. (43° C.). These crystals deliquesce at the ordinary temperature, giving an acid of specific gravity 1·063, which is a monohydrate. If the acid, specific gravity 1·05, be required for culinary purposes, pickling, &c., it is diluted with about five times its weight of water to render it of the same strength as revenue proof vinegar; a little caramel—burned sugar—dissolved in water, and occasionally a little acetic ether, are added to confer a deep colour, and give it aroma.

When the acid is required for the fabrication of the other compounds used in the arts and manufactures where great purity is not essential, it is prepared directly from the crude lime salt by distillation with sulphuric acid. In some of the Welsh factories the following is the mode of working:—A cast-iron cylinder, 4 feet long and 2 feet in diameter, having one end closed tightly by a stout iron door, the front end being secured by a door firmly screwed on, which may be removed at pleasure, is provided; this door is divided into two parts, the upper part being two-thirds, and the lower one-third of the whole. Through the upper division a stout iron rod passes, and runs along the length of the cylinder to the opposite end, where it is fixed in a groove. From that portion of the rod which is within the cylinder numerous bars project at right angles, and extend through the whole concavity of the cylinder. A movable door occupies the lower division of the front of the apparatus, through which the contents of the interior are withdrawn, and the convex part of the cylinder is furnished with an opening, to which a door is screwed; the apparatus thus completed is termed an *agitator*. The cylinder is placed horizontally in brickwork, and the opening in the upper part affords the means by which the proper quantity of acetate of lime and sulphuric acid is introduced, in the proportion of 100 of the former to 60 of the latter. After charging the cylinder, motion is communicated to the axis passing through the upper part of the door either by machinery or manual labour. When the contents of the agitator are completely comminuted, it is then drawn off by means of the movable door in the lower part of the front end into a vessel placed below to receive it, out of which the half liquid or pulpy mass is ladled into strong cast-iron trays of 3 to 4 feet in length, 2 feet wide, and about 2 inches in depth: these trays are afterwards deposited in an oven 5 feet long, 3 wide, and the same in height, being separated from one another by iron rods laid between them, and on which they rest. A pipe passes off from the far end of this case, by means of which the gaseous acetic acid is carried to the condenser, which is generally a stout leaden pipe, placed in a stream of cold water. Fire is applied directly to the bottom of the oven, and continued till the whole of the acid is expelled. The crude acid is thus procured in large quantities, and is for the most part forwarded to London for purification. The principal impurities are sulphurous acid, sulphur, and traces of sulphydric acid, arising from the action of the carbonaceous matters in the salt upon the sulphuric acid; and resinous and tarry bodies, with a large quantity of colouring matters. From these matters it is freed by redistilling with a little bichromate of potassa, or bicarbonate of soda. This second distillation is effected in leaden vessels, encased by a cast-iron cylinder.

The ordinary yield of acetic acid from 1 ton of the crude acetate of lime, when treated with 12 cwts. of rectified sulphuric acid, specific gravity 1·84, or 15 cwts. of acid of 1·77 and 1 ton of water, is 1½ ton of rough acid, of specific gravity 1·05. Copper stills, or cast-iron stills, with flat earthenware or tin heads, often serve for the second distillation.

To obtain acetate of lime in a sufficient state of purity, VÖLCKEL saturates the crude acid with lime without previous distillation, whereupon a part of the resinous impurities separates in combination with lime, while the rest remains in the liquid, imparting to it a dark-brown colour; the liquid is clarified by filtration, or by simply leaving the impurities to settle down, and afterwards evaporated in an iron pot to about one half its bulk. Hydrochloric acid is then added, which causes the dissolved resin to separate, and also decomposes the lime-compounds of creasote and other volatile substances. The resinous matters and lime salts collect together in the boiling liquor, so that they can be easily skimmed off, and the volatile oils are expelled during the evaporation. The quantity of hydrochloric acid required for this purpose varies, of course, with the constitution of the wood vinegar, which again varies with the degree of moisture of the wood from which the acid is obtained; but the weight is usually from 4 to 6 lbs. for 150 litres (33 gallons) of the wood vinegar, or as much as will communicate a slightly acid reaction to the liquor. The solution of acetate of lime is then further evaporated, and ultimately dried at a high temperature to expel all volatile substances. Evaporation and drying are generally performed in the same iron vessel; but in operating on a very large scale, it is best to dry the salt on cast-iron plates; the last operation requires very great care. The volatile empyreumatic substances adhere very tenaciously to the acetate of lime and to the resin contained in it, and unless driven off by heat they pass over in the subsequent distillation together with the acetic acid, and impart to it a bad smell; the desiccation must therefore be continued till the acetate of lime becomes inodorous or nearly so; when thoroughly dried it has a dirty brown colour.

To separate the acetic acid, the purified lime-compound is distilled with hydrochloric acid. The distillation may be performed in a still with copper head and leaden condensing tube. If the operation be conducted with proper care, neither copper nor lead is found in the distillate. The quantity of hydrochloric acid required cannot be exactly given, because the acetate of lime contains variable proportions of foreign matters, such as resin and chloride of calcium. In general, however, from 90 to 95 parts of hydrochloric acid of specific gravity 1·16, will completely decompose 100 parts of acetate of lime, without causing the distillate to be much contaminated with hydrochloric acid. In any given case the quantity of hydrochloric acid required is easily determined by an experiment on a small scale. The apparatus may likewise be so arranged as to allow of the subsequent addition of hydrochloric acid, if the quantity first used be found insufficient. Whether the amount introduced is sufficient may be known by testing the distillate with nitrate of silver; so long as mere turbidity only is produced, the hydrochloric acid is not in excess.

Distillation of the acetic acid proceeds with ease and regularity. The acetate of lime dissolves in the hydrochloric acid, forming a dark-coloured liquid, while a quantity of dark resin separates. As the whole mass is liquid, the heat diffuses through it easily; and as the acetic acid passes over between 212° and 248° Fahr. (100° to 109° C.), and the acetate of lime has been already exposed in drying to a higher temperature, the distilled acid is but very slightly contaminated with the empyreumatic products which result from decomposition of the resin; moreover, the resinous matters, being lighter than the chloride of calcium solution, float on the top, and do not form hard incrustations in the still.

The distilled acetic acid has only a very slight empyreumatic odour. It is perfectly colourless, and if hydrochloric acid has not been added in too great excess, gives but a slight cloud with nitrate of silver. Any yellow tint that it may exhibit arises from particles of resin carried over mechanically; for the resin, separated from the acetate of lime by the hydrochloric acid, melts as the temperature rises, and forms a fluid layer on the surface of the chloride of calcium solution which is very apt to cause spirting; the resin should therefore be removed as far as possible before distillation, either by skimming it with a spoon or by filtration through a linen cloth.

The specific gravity of the acetic acid obtained by VÖLCKEL's process varies from 1·058 to 1·061, and contains more than 40 per cent. of anhydrous acetic acid. As, however, acetic acid of this degree of concentration is rarely used, and as a somewhat weaker acid is more easily separated by distillation from the solution of chloride of calcium, it is better to add a certain quantity of water either before or towards the end of the distillation. A good proportion is 100 parts acetate of lime, from 90 to 95 of hydrochloric acid, and 25 of water; this gives from 95 to 100 parts of acetic acid, of specific gravity 1·015. In this manner 33 gallons of wood vinegar will yield 60 lbs. of acetic acid of the above strength.

Acetic acid thus obtained may be still further purified by mixing it with a small quantity of carbonate of soda and redistilling.

The acid which passes over is free from hydrochloric acid and perfectly colourless, but still retains a slight empyreumatic odour; but this may be removed by distilling it with 2 or 3 per cent. of bichromate of potassa instead of carbonate of soda. Acetic acid purified with bichromate of potassa is, in fact, undistinguishable from that which is obtained from pure acetate of soda by distillation with sulphuric acid, or from pure acetate of lime with hydrochloric acid. It does not exhibit the slightest colour when heated with strong sulphuric acid, nor does it reduce even the merest trace of silver when boiled with nitrate of silver and ammonia. When saturated with oxide of lead it yields a white salt, the analysis of which agrees perfectly with that of pure acetate of lead. Peroxide of manganese may be used instead of bichromate of potassa; but the acid when thus purified gives, after a time, a slight turbidity with nitrate of silver. Any empyreumatic odour that it may retain can be removed by digestion with pure animal charcoal. As acetic acid is easily freed from hydrochloric acid, a slight excess of the latter during distillation is not injurious, but is, on the contrary, very useful in the after purification of the acid with peroxide of manganese or bichromate of potassa.

Rectification of acetic acid with bichromate of potassa, or with the peroxide of manganese, is generally conducted in a copper still with a leaden condensing tube. The only contamination of acid thus prepared is a small quantity of acetate of lead; and if access of air be prevented during the distillation, this impurity will be confined to the first and last portions of the distillate: by collecting these portions apart, to be used for the preparation of acetate of lead, the acid may be obtained perfectly free from lead. By observing these precautions the operator may dispense with the use of glass or silver heads and condensing tubes. The entrance of air into the condensing tube may be prevented by closing the end of the tube with a cork, through which is inserted a glass tube, bent in the form ∽.

The preparation of acetic acid by the method just described may be rendered simpler by subjecting the wood vinegar to a previous distillation, and thereby removing the greater part of the resin before forming the lime salt. But this distillation obviously entails increased expense for labour and fuel, because the same liquid must be twice evaporated; moreover, part of the acetic acid remains with the tar in the retort. On the small scale, the loss thus occasioned is unimportant, but in a large manufactory it would amount to something considerable in the course of a year.

When, however, the wood vinegar has been previously distilled a compound still is unnecessary. The vapour is then, instead of being condensed immediately, made to pass into a copper receiver, containing the quantity of lime required to saturate the acid, and is thereby completely absorbed. If the copper receiver be surrounded by some substance which is a slow conductor of heat, very little aqueous vapour condenses, so that the steam may be advantageously used to concentrate a solution of lime resulting from a previous operation. This process is, however, more complicated, and yields no more acetic acid than the simpler one first described.

The method here recommended is much cheaper, and yields a much purer product than the ordinary method of distilling impure acetate of lime with sulphuric acid; further, by the addition of hydrochloric acid during the evaporation of impure acetate, the volatile slightly acid bodies contained in the wood vinegar are removed, according to SCHNEDERMANN, more easily than by the use of solution of chloride of calcium, or by roasting the impure acetate of lime either *per se* or with hydrate of lime. In the latter process, even if it attains the desired end, a considerable loss is incurred from decomposition of the acetate of lime, inasmuch as that substance, from its infusibility, does not admit of any exact regulation of the heat.

The use of hydrochloric, instead of sulphuric acid, in the decomposition of the acetate of lime, has this great advantage, that the presence of resin, colouring matter, &c., in the acetate of lime, is harmless, provided that the salt has been sufficiently heated to drive off the free volatile substances. When, on the contrary, sulphuric acid is used, the acetic acid produced has always a bad odour, is saturated with sulphurous acid, and contaminated by a variety of products arising from the deportment of the resins at an elevated temperature. The sulphate of lime produced also forms a hard crust at the bottom of the retort, and in distilling on the large scale the under part of the alembic must be heated completely to redness to drive out all the acetic acid. The last portions of acid that pass over are moreover often turbid from sulphur, and the odour of sulphuretted hydrogen becomes perceptible, that gas arising from reduction of the sulphate of lime to sulphide of calcium at the bottom of the vessel; from these causes the cast-iron retorts soon become corroded.

Pure acetic acid may be obtained by the method above described at so very low price that it may be advantageously used in the preparation of acetates, especially of acetate of lead.

An important improvement in the purification of acetic acid was patented by H. B. CONDY in 1868. It has long been known that a solution of acetate and chloride of calcium, in equivalent proportions, yields by slow evaporation large crystals containing $CaCl,CaC_2H_3O_2 + 5H_2O$, calcium aceto-chloride. H. B. CONDY has found that, by judicious manipulation, these crystals are readily formed, and in a state of great purity, even when black and brown acetate of lime is operated on. From the pure double salt he obtains pure acetic acid by adding to it a strong acid and distilling.

For the manufacture of the calcium aceto-chloride for the subsequent manufacture of pure acetic acid, any inferior acid, such as that obtained by the distillation of commercial acetate of lime with sulphuric or muriatic acids, may be employed; but the most practical and economical plan is to take 8 cwts. of commercial acetate of lime, known as distilled acetate of lime, and dissolve it by boiling in 500 gallons of water. This is filtered or allowed to settle till the next day, when a quantity of dry chloride of calcium, equal in weight to seven-tenths of the acetate of lime employed, is dissolved in it by heat and agitation. If commercial chloride of calcium, or a strong solution of chloride of calcium, is used, it is necessary to take into calculation the water present, and to employ an additional quantity of chloride in compensation. This mixed solution of acetate and chloride of calcium, containing, in addition to the quantity necessary to form the aceto-chloride, an excess of about 20 per cent. of chloride, is brought by careful management when boiling hot, or nearly so, to the specific gravity of 30° Beaumé; if it should be of a lower specific gravity it is evaporated to this strength; if it be too strong it is diluted to the same point, and then drawn off to crystallize. When cold, and a crop of salt (aceto-chloride) has crystallized out, the mother liquor is drawn off and evaporated down till the hot liquor shows a strength of 31° Beaumé, when it is again drawn off to crystallize. These evaporations and crystallizations are repeated until three other crops of aceto-chloride are obtained. For the third crop the liquor drawn off boils at about 33° Beaumé, for the fourth at about 35° Beaumé, and for the fifth about 36° Beaumé. These five crops are of tolerably uniform quality, and leave by far the greater part of empyreumatic matter in the last mother liquor, which has given up nearly all its valuable and available acetate in the form of crystal, and is then either rejected, or it may be distilled with sulphuric or hydrochloric acid for producing an inferior acetic acid.

For manufacture of the pure salt these five crops, after they have been well washed and drained, are redissolved in twice their weight of water, the solution filtered through animal charcoal, and a further quantity of 10 per cent. or thereabout of chloride of calcium is added, after which the liquor is evaporated to 29° Beaumé, at which strength a good crop of white salt is obtained. The mother liquors from this salt are again evaporated down, and the hot liquor drawn off to crystallize at 30° Beaumé to obtain a second crop, at 31° for a third crop, and at 32° for a fourth crop. The mother liquor is then turned into the original solution of calcium aceto-chloride, from which the first of the five crops of rough salt referred to has been obtained.

Commercial brown acetate of lime, or even crude pyroligneous acid, may be employed for this process, but not with the same advantage. In the case of brown acetate of lime, it is necessary to observe that the weight of acetate of lime employed should be 20 per cent. more than that of "distilled" for a given weight of chloride of calcium, *i.e.*, about 12 parts brown acetate to 7 parts dry chloride; that the specific gravity of the liquor drawn off for obtaining each crop of salt (aceto-chloride) must be adjusted or regulated by experiment, since no two samples of brown acetate of lime are quite alike, and that it will depend in each case on the care with which the acetate may have been prepared. This can be ascertained during the process of evaporation by cooling and crystallizing a sample, after the boiling or hot liquor has attained 30° Beaumé. If after cooling a good crop of salt is not obtained, the liquor must be evaporated further until that object is accomplished. To obtain this salt by the employment of crude pyroligneous acid it is necessary to neutralize with lime, and to estimate the quantity of dry brown acetate it contains by evaporating a small portion to dryness and weighing the product. If the solution contains 1 part of brown acetate in 10 parts it will be simply necessary to bear in mind that 12 parts of the dry acetate in it require 7 parts of chloride of calcium, and that for the first crop it must be evaporated to 32° Beaumé; the tendency to crystallize must then be estimated by taking out a hot sample and allowing it to cool, and again evaporating until the required strength for crystallization is obtained. As a rule the mother liquors in all cases require to be evaporated to half their bulk to yield a further crop of salt, and then the tendency to crystallize can be ascertained.

When working upon commercial acetate of lime, the acetate is previously roasted so as to destroy some of its impurities. For this purpose a large iron retort is employed, 3 feet 6 inches in diameter, and 6 feet long; near the bottom a grating is so arranged as to touch the sides of the retort at a few points only, in order that conduction of heat from the sides may be but small. The acetate of lime is placed in sheet-iron trays about 2 inches deep, which are placed in the grating one over the other until the retort is filled; the trays are separated by iron rods laid in between them, and care is taken to keep them out of contact with the sides of the retort. The retort is then gradually fired until the outlet or head passing from the retort becomes heated by the escape of steam, after which the fire is steadily kept up but not raised higher until this escape pipe commences again to cool down, which indicates that the greater part of the water and the impurities have been driven off. The fire is now let out, and when cool, or nearly so, the charge is drawn. The operation generally takes about forty-eight hours for its completion.

When a solution of acetate of lime obtained by neutralizing impure acetic acid is operated upon, the aceto-chloride may be similarly roasted before redissolving and recrystallizing it. Roasting the aceto-chloride may also be done when working on commercial acetate of lime in place of roasting the acetate. Or in lieu of roasting, the original solution of acetate and chloride, or the acetate of lime alone, is sometimes filtered through animal charcoal, which has a remarkable affinity for, or power of, separating the empyreumatic impurities from the aceto-chloride, and also, though in a much less degree, from acetate of lime.

To make acetic acid, the calcium aceto-chloride, purified by crystallization, is decomposed with hydrochloric, sulphuric, or any other acid having sufficient affinity for lime to liberate the acetic acid contained in the salt, and the acetic acid separated from the chloride, and sulphate, or other calcium salt, by distillation.

The plan adopted is as follows:—To 112 parts of calcium aceto-chloride, 24 parts of sulphuric acid, spec. grav. 1·845, or thereabout, diluted with twice its volume of water, are added; these materials having been well mixed, are then distilled, and the acetic acid condensed in the usual manner. To render this acid quite pure, *i.e.*, free from hydrochloric acid, it is again distilled off alkali or acetate of soda, employed in the proportion of 1 lb. to 10 gallons of acid.

Another method is to take of aceto-chloride of calcium 100 parts, and of hydrochloric acid, spec. grav. 1·160, 50 parts each by weight, and after carefully dissolving the former in the latter, distilling off the acetic acid and condensing it as usual. This operation is performed in a suitable still, and in the manner usually followed in the manufacture of acetic acid by the decomposition of acetate of lime with hydrochloric acid. This acid is also redistilled with sufficient alkali to retain any slight trace of hydrochloric acid which may have passed over with the vapour in the first operation. The aceto-chloride is frequently sent into the market to be used by the purchaser as a convenient source of acetic acid. This process has the great advantage over many others that the preparation of the aceto-chloride can be conducted on the spot where wood is distilled, as for example, in foreign countries where wood is cheap, and may then be imported into this country for the process of producing the pure acetic acid to be completed.

A patent was taken out in 1873 by John Steedman, of Glasgow, for a process for the purification of acetic acid by passing the crude vapours through some hydrocarbon (preferably paraffin), kept at the temperature of the distillate, in order to separate the empyreumatic matters before condensation. The impurities are retained by the hydrocarbon, and the acid vapour passes on in a pure state to ordinary condensers, whilst the hydrocarbon is renewed periodically as it becomes charged with the impurities.

The process may be practically carried out in any convenient vessel or apparatus, in which the crude acetic acid vapours can be brought into intimate and continued contact with the purifying substance. Messrs. Steedman & M'Alister employ a copper vessel of a rectangular form, about 5 feet long, 1 foot wide, and 2 feet 9 inches deep. This vessel is fitted internally with three partitions of copper or wood, which are horizontal in cross section, but slightly inclined longitudinally. The partitions are open at alternate ends, and the vessel being filled with paraffin, the acetic acid vapour, which is introduced from the usual distillatory apparatus by a pipe leading in beneath the closed end of the lowest partition, travels along through the paraffin from end to end beneath the partitions, and is finally led from the top of the vessel to ordinary condensing apparatus. The paraffin is kept sufficiently heated by a coiled steam pipe, or steam jacket, or in any other convenient way, and is withdrawn from the vessel whenever it is fully charged with impurities from the acetic acid. If wished, the acetic acid may be passed successively through two or more vessels containing the purifying substances. In practice it is found to be convenient to use the "heavy oil" for the separation of the grosser impurities, and to pass the acid afterwards through ordinary paraffin for further purification. A purifying vessel of the above dimensions is suitable for use in connection with a still of a size usually receiving about 100 gallons at a charge.

A large portion of the impurities taken up by the paraffin may be separated therefrom by agitation with hot water; and the paraffin may be further purified by the processes ordinarily employed for that purpose, and is then again fit for use as before. The heavy oil may be purified by ordinary processes.

Of late years woody fibre has been much used for paper-making and analogous purposes; various patents have therefore been taken out, having for their object the extraction of the acetic acid, methylic alcohol, resin, &c., without carbonization:

that of George Fry, in 1869, may be quoted as typical.

The first process is the cutting of the wood into strips or small pieces. The sizes of the slips into which it is preferable to cut the wood intended for paper-making are from half an inch to an inch and a half in length, and from one-eighth to one-quarter of an inch in thickness. If the slips are less than half an inch in length the fibre is liable to be too much cut and too short; and if they are more than an inch and a half in length, the boiling must be continued for a longer time, as the saturation of the wood takes place principally in the direction of the grain, so that the shorter the fibre the more perfect the saturation. On the other hand, it is found that a thickness of from one-eighth to a quarter of an inch is the most convenient size for the subsequent process of rolling and pressing to fit it for paper pulp. It is especially desirable that all the pieces of wood operated upon at one time should be of one uniform length and thickness, in order that the saturation of and pressure on all the fibre may be equal. The wood after being cut into suitable pieces is placed in cages (made of perforated zinc or copper wire) that exactly fill the inside of the inner cylinder of the boiler B (see Figs. 26 and 27). These cages are then placed in the boiler, the cover C is put on, and water is pumped into the boiler so as to fill it, with the exception of a small space left for expansion. By means of the steam jacket described below the boiler is then heated. The degree of heat that has been found most effectual for the purpose is that yielded by steam of 70 to 100 pounds pressure to the square inch, or equal to about from 300° to 330° Fahrenheit. This heat must be continued for from three to five hours, according to the nature of the wood and the size of the pieces. The heat employed may be greater, and if so the time of the boiling will be proportionately less, but that above indicated is preferred in practice.

Fig 26.

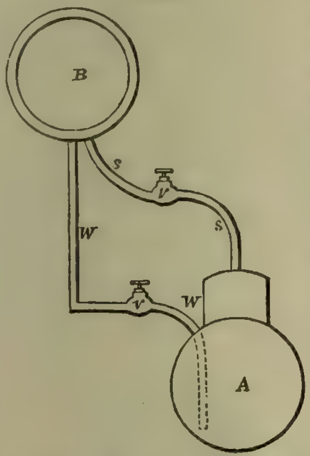
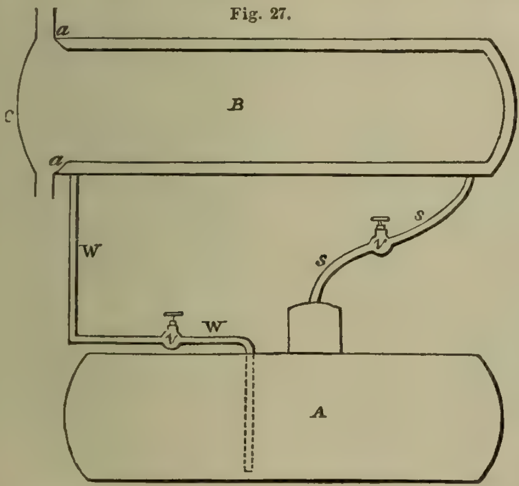


Fig. 27.



In the diagrams (Figs. 26 and 27) A represents any suitable boiler for generating high pressure steam; B is a boiler with a steam jacket, that is to say, it is composed of two cylinders of wrought iron rivetted together at *a*, *a*; C is a movable cover (to allow of the introduction and withdrawal of a cage containing wood) fastened to the flanged end of the boiler by means of stout bolts and nuts; S is a pipe for conveying steam from the steam chest of the generating boiler, A, to the space between the two cylinders of B; V is a valve which can be opened and shut at pleasure; W is a pipe dipping into the water of the boiler, A, down which the condensed steam returns from the steam jacket of B into A; V* is a valve so constructed that it is closed by pressure from A to B, but opened by pressure from B to A, by which means water can pass from B to A, but not from A to B. The cage or cages containing strips of wood being placed in the inner chamber of B, the cover C is bolted on and water is pumped into this chamber. The valve V is then opened. As soon as the pressure in the steam jacket of B approaches that in the generating boiler, A, the condensed steam (now water) passes freely from B back into A, and the contents of the inner chamber of B become rapidly heated by the steam supplied by the pipe, S, to the jacket.

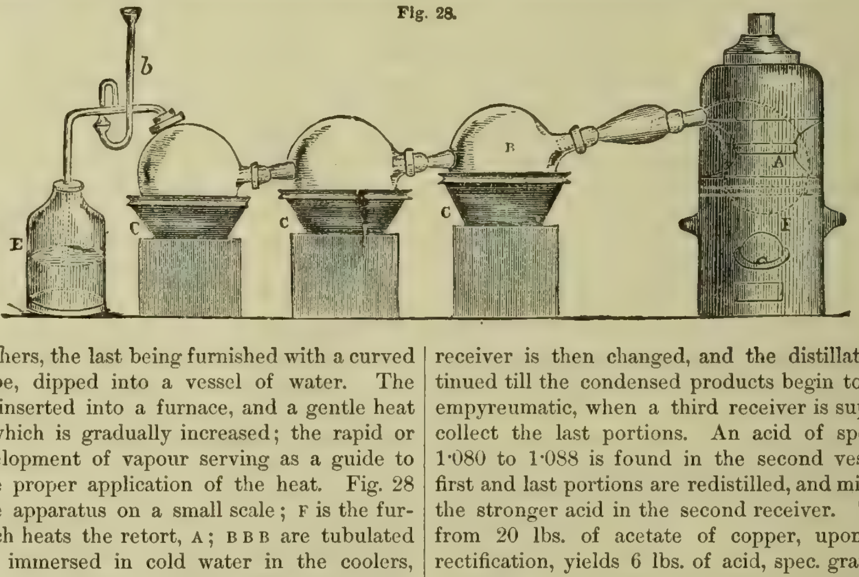
The object of the peculiar arrangement of boiler referred to is to prevent the burning or charring of either the fibre or the liquid, to which it would be liable in ordinary boilers. When the wood has been sufficiently boiled the steam is shut off from the jacket of the boiler, and a valve opened in the pipe through which liquid is conveyed to and from the inner chamber of the boiler. The liquid in which the wood has been boiled then passes first through a coil of copper pipe placed in a cistern of cold water (renewed constantly during the passage of the liquid), and next through a box strainer of fine wire gauze into a still or retort. This still is heated in the usual manner by means of high pressure steam, and the liquid in which the wood has been boiled is distilled.

The first part of the distillate consists of dilute spirit (wood spirit, oil of turpentine, or other spirit, according to the kind of wood operated upon), and the latter part of dilute acetic acid. The spirituous liquid is rectified in the usual way, by which the greater part of the water is separated from the spirit. The acid liquid is run into an evaporating pan, where it is neutralized by an alkali, and then after evaporating the water by a gentle heat the acetate of the base remains. In order to obtain the almost anhydrous acid it is only necessary to mix gradually a strong acid (such as hydrochloric or sulphuric acid) with the acetate in sufficient quantity to take up the base, and to pour or distil off the acetic acid thus set free. The residuum (or solid matter left in the still) consists of rosin or resin, sugar, and a compound of iodine, the only part of which at present utilized is the resin. This is isolated by washing the residuum with water on a filter, the resin being insoluble in water, is precipitated in small crystals, from which the other matters being soluble are washed. As soon as pressure in the boiler has ceased by allowing the liquid to escape as above described, the cover C is removed, the cages are drawn out, and the wood fibre is passed between strong pressure rollers, or a hydraulic press may be used. The expressed liquid is passed into the still with the liquid obtained from the boiler. For the manufacture of paper the fibre is thrown into a washing or rag machine, and reduced to pulp. After washing it may be bleached as occasion may require by the usual process, viz., the action of chlorine, either alone or aided by an alkali or an acid. If the fibre is to be used for cordage the wood must be cut into strips of greater length, the boiling must be continued longer, and after rolling and pressing the fibre must be carefully washed.

Pure Acetic Acid from Brandy Vinegar.—By Völckel's process, brandy vinegar which contains from 12 to 15 parts of anhydrous acid is saturated with lime, and the solution strained through a linen cloth, and evaporated in an iron vessel. The dried salt is perfectly white. The decomposition of the acetate of lime is effected by hydrochloric acid, but the acetate of lime being less feculent than that obtained from wood vinegar, more hydrochloric acid is required for its decomposition. The amount used is about 130 parts of acid to 100 parts of the lime salt. Final purification is effected as usual.

Aromatic Vinegar.—Crystallized acetate of copper is the salt most usually employed: 20 lbs. of the powdered acetate of copper are introduced into an earthen retort of about 2 gallons capacity; the retort is luted and carefully dried before applying heat to distil the acid, and by this precaution it lasts much longer. The elongated neck of the retort is connected with a tubulated receiver; this is joined to several others, the last being furnished with a curved safety-tube, dipped into a vessel of water. The retort is inserted into a furnace, and a gentle heat applied, which is gradually increased; the rapid or slow development of vapour serving as a guide to direct the proper application of the heat. Fig. 28 shows the apparatus on a small scale; F is the furnace which heats the retort, A; B B B are tubulated receivers, immersed in cold water in the coolers, C C C; the last receiver, B, has a Welter's safety tube, *b*, the long arm of which dips into the water in E, where any uncondensed vapours from the receivers are absorbed. The fire in F is lighted, and the heat gradually raised so long as any vapours pass over; when no more vapours are given off, the distillation is terminated, the fire is withdrawn, and the apparatus allowed to cool: 20 lbs. of the copper salt produce, by distillation, about 10 lbs. of rough acid, of a greenish colour, and 1·061 spec. grav.; the residue in the retort consists of 6½ lbs. of metallic copper, mixed with a small quantity of charcoal. The crude acid is then rectified in a glass retort of the capacity of about 1½ gallon, to which is adapted a tubulated receiver, and heat applied by means of a sand-bath. A weak acid comes over first, which is collected separately until it acquires a density of 1·072; the receiver is then changed, and the distillation continued till the condensed products begin to become empyreumatic, when a third receiver is supplied to collect the last portions. An acid of spec. grav. 1·080 to 1·088 is found in the second vessel; the first and last portions are redistilled, and mixed with the stronger acid in the second receiver. The acid from 20 lbs. of acetate of copper, upon second rectification, yields 6 lbs. of acid, spec. grav. 1·085; 3 lbs. spec. grav. 1·042; and half a lb. of acid, spec. grav. 1·023.

Fig. 28.



Other metallic acetates may be used, but yield variable amounts of acid. The acetates of copper, silver, mercury, lead, &c., afford a larger proportion of acetic acid. Acetone, carbonic oxide, carbonic acid, and marsh gas, are evolved in various proportions; the metal of the salt is invariably left in the retort. The acetate of silver gives off no acetone when submitted to destructive distillation. Acetates, the metals of which retain carbonic acid at a red heat, produce chiefly the carbonate of the base and acetone, but very little acetic acid: the acetates of potassa, soda, and baryta behave in this manner; but when the metal cannot retain carbonic acid at a red heat, as in the case of the acetates of magnesia, zinc, and manganese, the acetone is accompanied by carbonic acid, and the oxides of such metals remain in the retort.

The small amount of acetone which passes over with the acetic acid, in the distillation of acetate of copper, imparts an agreeable aroma; and by the addition of a little camphor or essential oils, the *aromatic vinegar* of commerce is produced.

ACETIC ACID AND VINEGAR TESTING. — The specific gravity of vinegar is sometimes ascertained by a species of hydrometer, termed an *acetometer*. By dipping it into the vinegar under examination, and observing the depth to which it sinks, the number of the scale marking the level of the liquid indicates the density of the solution, from which, by means of a table, the percentage of real acid is ascertained. The results vary for different temperatures, as may be seen by the following table, compiled by OUDEMANNS, according to whom MOHR'S determinations were made, not with pure glacial acetic acid, but with an acid containing 5 per cent. of water:—

Acetic Acid, $C_2H_4O_2$ per cent.	Density.		Acetic Acid, $C_2H_4O_2$ per cent.	Density.	
	15° C.	40° C.		15° C.	40° C.
1	1·0007	0·9936	51	1·0623	1·0416
2	1·0022	0·9948	52	1·0631	1·0423
3	1·0037	0·9960	53	1·0638	1·0429
4	1·0052	0·9972	54	1·0646	1·0434
5	1·0067	0·9984	55	1·0653	1·0440
6	1·0083	0·9996	56	1·0660	1·0445
7	1·0098	1·0008	57	1·0666	1·0450
8	1·0113	1·0020	58	1·0673	1·0455
9	1·0127	1·0032	59	1·0679	1·0460
10	1·0142	1·0044	60	1·0685	1·0464
11	1·0157	1·0056	61	1·0691	1·0468
12	1·0171	1·0067	62	1·0697	1·0472
13	1·0185	1·0079	63	1·0702	1·0475
14	1·0200	1·0090	64	1·0707	1·0479
15	1·0214	1·0101	65	1·0712	1·0482
16	1·0228	1·0112	66	1·0717	1·0485
17	1·0242	1·0123	67	1·0721	1·0488
18	1·0256	1·0134	68	1·0725	1·0491
19	1·0270	1·0144	69	1·0729	1·0493
20	1·0284	1·0155	70	1·0733	1·0495
21	1·0298	1·0166	71	1·0737	1·0497
22	1·0311	1·0176	72	1·0740	1·0498
23	1·0324	1·0187	73	1·0742	1·0499
24	1·0337	1·0197	74	1·0744	1·0500
25	1·0350	1·0207	75	1·0746	1·0501
26	1·0363	1·0217	76	1·0747	1·0501
27	1·0375	1·0227	77	1·0748	1·0501
28	1·0388	1·0236	78	1·0748	1·0500
29	1·0400	1·0246	79	1·0748	1·0499
30	1·0412	1·0255	80	1·0748	1·0497
31	1·0424	1·0264	81	1·0747	1·0495
32	1·0436	1·0274	82	1·0746	1·0492
33	1·0447	1·0283	83	1·0744	1·0489
34	1·0459	1·0291	84	1·0742	1·0485
35	1·0470	1·0300	85	1·0739	1·0481
36	1·0481	1·0308	86	1·0736	1·0475
37	1·0492	1·0316	87	1·0731	1·0469
38	1·0502	1·0324	88	1·0726	1·0462
39	1·0513	1·0332	89	1·0720	1·0455
40	1·0523	1·0340	90	1·0713	1·0447
41	1·0533	1·0348	91	1·0705	1·0438
42	1·0543	1·0355	92	1·0696	1·0428
43	1·0552	1·0363	93	1·0686	1·0416
44	1·0562	1·0370	94	1·0674	1·0403
45	1·0571	1·0377	95	1·0660	1·0388
46	1·0580	1·0384	96	1·0644	1·0370
47	1·0589	1·0391	97	1·0625	1·0350
48	1·0598	1·0397	98	1·0604	1·0327
49	1·0607	1·0404	99	1·0580	1·0301
50	1·0615	1·0410	100	1·0553	1·0273

Vinegar made from dilute alcohol or ripe wines, in which no great excess of albuminous and other matters is present, can to a certain limit be tested with sufficient accuracy by the acetometer; but vinegars made from malt, poor wines, and such liquids as contain an excess of organic matters, do not admit of being tested with the required degree of accuracy by this method, since the apparent quantity of real acetic acid is increased by the presence of foreign bodies, which add to the density of the liquid. In some cases the vinegar is saturated with chalk or milk of lime, the solution filtered, and the specific gravity of the acetate of lime liquor ascertained, by which a nearer approximation is arrived at than by the direct testing of the vinegar; yet on neither of these two methods can implicit reliance be placed.

The most common method of ascertaining the percentage of acetic acid in vinegar is to neutralize it with pure carbonate of potassa or soda, noting the quantity of these salts required to saturate the acid. The amount of real acid in a sample is then ascertained by a simple calculation, since every 106 grains of the pure carbonate of soda, or 138 grains of the carbonate of potassa—one equivalent—indicate 120 grains, or two equivalents, of pure acetic acid. The examination is made in the following manner:—530 grains of pure dry carbonate of soda are dissolved in 10,000 grains of distilled water—ten alkalimetrical measures. This mixture constitutes the test solution, and is kept in a stoppered bottle for use. An ounce of the vinegar is either weighed or measured, and put into a beaker or porcelain dish, and 1000 grains of the test solution—equal to 100 divisions of the burette—are poured, in successive small portions, into the vinegar, the solution being well agitated with a glass or porcelain rod after each addition. The solution is tested at intervals with blue litmus paper, and so long as its colour is reddened when dropped into the liquid, and the effervescing continues, free acid still remains in solution, and more test solution must be added. When the saturation of the vinegar is nearly complete, heat is applied to expel the carbonic acid which is absorbed, and would, if not driven off, communicate a faint rose tint to the test paper, and thus cause an error in the results. If the paper still becomes red after heating, a few drops more of the alkaline liquor are poured in, till the paper is only feebly reddened. Sometimes a few drops of tincture of litmus are added to the acetic acid to be tested; as the operation draws to a close the litmus regains in part its blue colour. This plan, however, offers no advantage, for the acid may be completely saturated long before the colour of the blue litmus is restored. The number of divisions of the test liquor required to saturate the acid is read off, and by a *rule of three* calculation the amount of acid in the sample is found.

Fig. 29 represents GAY-LUSSAC'S burette. BINK'S burette, Fig. 30, is much less fragile; the solutions are, however, liable to run down outside the spout, *a*. This can be prevented by applying a little stiff tallow to the spout, and boring through it a small hole with a needle. To manage this instrument properly it must be held near the top, the thumb being placed above the scale. If it be held lower down the delivery of single drops is difficult. The most convenient of all forms of burette is that of Mohr, Fig. 31. *a* is a cylindrical tube which is graduated into 100 parts, 0° being at the top and 100° at the bottom. The tube is open at both ends, but the lower end is contracted, and is connected by a short flexible tube of vulcanized caoutchouc with a small glass jet, *c*. Across the flexible tube is placed a pinch-cock, *d*, which closes the tube when left at rest, and opens it when the buttons at *d* are slightly pressed with the finger and thumb. It is easy either to let out a continuous stream of the test liquor, or to limit its passage to single drops. The burette is suspended by a ring of cork or caoutchouc from the upper arm, *e b*, of the support. The lower arm serves to keep the burette in a vertical position. The point, *c*, is fixed at such a height above the table as to allow free access to the vessel containing the liquid to be tested.

Fig 29.

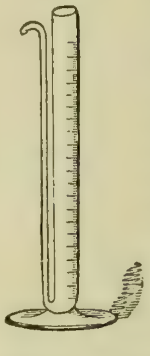


Fig. 30.

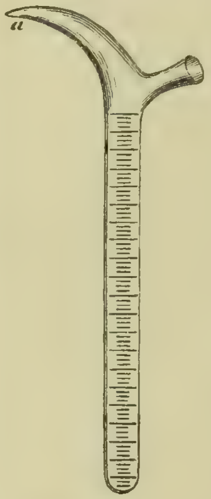
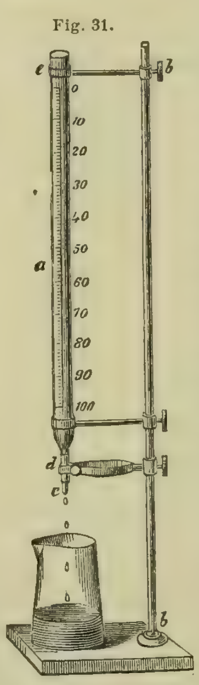


Fig. 31.

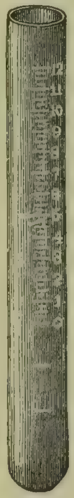


Instead of a soda test liquor, a solution of ammonia is sometimes used to saturate the acid. This solution is prepared by adding water to concentrated ammonia till the spec. grav. is 0·992: 1000 grains of this dilute ammonia contain one equivalent of ammonia, which is capable of saturating one equivalent of acetic acid. The application of this test is similar to that already described.

There is some difficulty in preserving the dilute ammonia of the same strength, which is an objection to its use; but a uniformity of concentration is insured by introducing into the bottle two glass hydrometer bulbs, so adjusted that one remains barely touching at the bottom, and the other floats just under the surface of the liquid, as long as the test liquor maintains the proper strength. If a part of the ammonia volatilizes, the specific gravity of the liquor will become proportionably greater, and the glass bulbs rise; the lower one higher from the bottom, and the upper one partly above the surface. When this happens more strong ammonia is added, till the hydrostatic drops are properly readjusted.

Otto's acetometer, Fig. 32, is a glass tube sealed at one end, 36 centimètres long by 1·5 centimètres wide; upon it two scales are engraved, one at the bottom for measuring the vinegar, and the scale at the top for measuring the test liquor. His mode of operation is to pour a certain quantity of litmus solution into the tube, and then sufficient vinegar to fill it up to where the upper scale begins. The test liquor, containing 1·369 per cent. of ammonia, is then added until the blue colour of the litmus is restored; the quantity required of course indicates the percentage of acetic acid.

Fig. 32.



These methods are slightly inaccurate, in consequence of neutral acetates of the alkalies themselves exhibiting an alkaline reaction. The error, however, has been shown by Otto to be less than 0·1 per cent. for an acid containing 10 per cent. of crystallizable acetic acid. It may, moreover, be avoided by using a test solution which has been graduated for the purpose by means of a solution of pure acetic acid of known strength.

Greville Williams advocates the use of lime saccharate. To prepare this test liquid lime is dissolved in a moderately strong solution of sugar. The solution, after filtering, has its strength ascertained by means of a standard sulphuric acid solution, and is then diluted until five divisions of the burette correspond to one grain of acetic acid. To perform this experiment fifty grains of the sample to be examined are taken and made up with water into about two ounces of liquid, a few pieces of litmus paper are then thrown in and the test liquid carefully added, with constant stirring, until the blue colour of the litmus is restored. With moderate care the results do not vary, and in rapid work can be relied on to 0·25 per cent.

In each of the preceding modes of testing it is evident that, should the vinegar contain any admixture of other acids, such as sulphuric acid, hydrochloric acid, or the like, these will increase the quantity of the alkaline solution required to neutralize the weight of vinegar taken for the test. Preliminary examinations should be made to ascertain if these impurities be present, and if so, their amount determined.

Sulphuric Acid in Vinegar.—After the conversion of malt, beer, weak wines, &c., into vinegar, a putrid fermentation often takes place which decomposes the whole of their acetic acid. It was formerly considered necessary that sulphuric acid should be added to counteract this tendency of the liquid to decomposition, and to preserve it from turbidity. This addition was permitted to the extent of 1 gallon of sulphuric acid to 1000 gallons of vinegar, by an excise regulation, and had therefore a legal sanction. Sulphuric acid is now known to be unnecessary in properly prepared vinegars, although it is still added by some manufacturers for the purpose of increasing the strength of their vinegars, or in some instances merely from habit and the indisposition to disturb the routine of an old-established practice. Sulphuric acid in vinegar should invariably be looked upon as the mark of inferior quality; for it is only where the mode of manufacture is defective that its addition is at all necessary. Sulphuric acid does not in the least favour digestion, and it is known that it affects the coats of the stomach. Besides the addition of the $\frac{1}{1000}$ part of sulphuric acid, many persons—makers or vendors—add a far greater proportion in order to confer that acidity which ought only to be produced by the acetic acid. Some of these mixtures are most dangerous to the community, as the commonest oil of vitriol is often used as the adulterant. Vinegars adulterated with pyrites vitriol also generally contain arsenic.

Several methods have been given by chemists for the detection of sulphuric acid in vinegar or acetic acid. Here will be enumerated a few of the more trustworthy for the qualitative and quantitative estimation of sulphuric acid in vinegars. It should, however, be borne in mind that vinegar made from wine, malt, &c., contains some soluble neutral sulphates, these being natural constituents of the grain or grapes from which the wine or fermented wort is obtained; and that by the more delicate tests this quantity of sulphuric acid in combination will be indicated.

If the vinegar be suspected to contain a greater quantity of sulphuric acid than that which is authorized, it may be ascertained pretty accurately by making a solution of 1 part of sugar in 30 parts of water, bringing the liquid to a temperature of 190° or 200° Fahr. by means of steam heat, and then adding a drop of the suspected vinegar. If sulphuric acid in excess be present it will carbonize the sugar, causing a blackish spot to appear at the point where the vinegar came in contact with the saccharine solution. This happens when the vinegar contains the $\frac{1}{300}$th of its weight of the adulterant. When the amount ranges between the $\frac{1}{600}$th and $\frac{1}{800}$th of the impurity, a greenish spot appears.

The next and principal test is the precipitation of the sulphuric acid by means of a soluble salt of barium, in the form of insoluble barium sulphate ($BaSO_4$), which falls down as a heavy white powder. A correct inference may be drawn as to whether the vinegar contains more than the ordinary amount of sulphuric acid, by observing the bulk of the precipitate. An immediate white precipitate indicates the presence of sulphuric acid, when only about the $\frac{1}{800}$th or $\frac{1}{1000}$th of the adulterant is present; but this precipitate does not so quickly subside as when larger quantities are present.

Sulphuric acid is determined quantitatively in the following way:—Half a pound of the vinegar is evaporated in a porcelain or platinum basin, on a water-bath or by steam heat, till the eight ounces are reduced to one ounce; the basin is then removed from the heat and allowed to cool, and five to six times its bulk of strong alcohol is added. The earthy and alkaline sulphates naturally present in the vinegar are insoluble in alcohol, and consequently fall down. After the precipitate has subsided, the solution is filtered off, and the residue washed with dilute spirit. The greater part of the alcohol is then expelled by evaporation in the water-bath, the remaining liquid diluted with ten or twelve times its volume of water, and a solution of chloride of barium poured in as long as a precipitate is formed. The precipitate, after subsidence and filtration of the supernatant liquid, is digested with moderately dilute warm hydrochloric acid, then thrown upon a filter, washed with boiling water till a portion of the washings gives no white precipitate upon addition of sulphuric acid, dried in a water or air bath, and when dry, burned in a platinum crucible. The precipitate should be detached as much as possible from the filter-paper, and the latter burned in the crucible until the whole of the carbonaceous matter of the paper is destroyed, and the precipitate then introduced, heated to redness, and weighed. Every 233 parts of this precipitate ($BaSO_4$) indicate 98 parts of sulphuric acid (H_2SO_4).

When great accuracy is not required, a standard solution of barium chloride is used: 500 grains of vinegar, diluted with twice its weight of water, are poured into a tall and not very wide beaker glass, or precipitating jar, and the graduated burette is filled, and the standard solution poured gradually into the vinegar, in small portions at a time, the mixture being well stirred with a glass rod after each addition; the whole left to rest in a warm situation till the precipitate has collected at the bottom, after which another addition of the test solution is made, observing the same rule as above given, so long as any precipitate forms. When the last drop causes no precipitate, or at least only a very slight one, the number of measures of test solution added are read off, and from this the amount of sulphuric acid is calculated.

Some spring and river waters contain a large quantity of sulphates, in which case a greater amount of the test solution will be required than for the free sulphuric acid in the vinegar; an examination of the water employed should therefore precede the testing of the vinegar, or the analysis should be conducted by the first method described, namely, evaporation of the vinegar, and treatment with alcohol before precipitation.

HYDROCHLORIC ACID IN VINEGAR.—This acid is not frequently met with in vinegar. Its presence may be ascertained by distilling a quantity of the vinegar from a glass retort, to which a condenser is attached, and adding a few drops of a solution of silver nitrate to the distillate. A white precipitate indicates the presence of hydrochloric acid. To determine quantitatively the amount of the acid, 8 or 16 ozs. of the vinegar are distilled, till the whole of the liquid has passed over into the receiver. A solution of silver nitrate is poured into the distillate as long as a precipitate occurs. The solution is left at rest till the white curdy precipitate of silver chloride falls to the bottom, which is filtered off, washed with a little dilute nitric acid first, and afterwards with distilled water; dried at 212° Fahr. (100° C.) in a water-bath, ignited in a porcelain crucible, and weighed. From the weight of the silver chloride, that of the hydrochloric acid is calculated.

Nitric Acid in Vinegar.—This acid is rarely employed to adulterate vinegar. If its presence be suspected, about 8 ozs. are neutralized with sodium carbonate, the liquid evaporated to dryness, and the residue distilled with a few drops of strong sulphuric acid. The distillate is received in an ice-cold receiver, neutralized with potassa, and a solution of starch paste and potassium iodide added. Iodine forms a deep indigo blue compound with starch, which is soluble in pure water, but insoluble in solutions containing free acid; if a blue colour appears, it is an infallible proof of the presence of nitric acid. A simpler test is to boil a portion of the residue of the vinegar after evaporation with hydrochloric acid and copper turnings; if nitric acid be present, red fumes of nitrous acid, possessing a very characteristic vapour, are evolved.

Tartaric Acid in Vinegar.—On evaporating a portion of the vinegar in a water-bath, if tartaric acid be present, a viscid mass of the consistence of treacle, and highly acid, remains. By adding alcohol to this substance, and agitating for a short time, the tartaric acid is dissolved; the spirituous extract is then filtered off, mixed with potassium chloride, and well agitated, upon which it yields a crystalline precipitate of potassium bitartrate ($KC_4H_5O_6$)—cream of tartar—in the presence of tartaric acid. It must be remarked that wine vinegar naturally contains some tartaric acid in the form of cream of tartar—this compound being one of the solid constituents of the grapes.

Metallic Salts in Vinegar.—The salts which are formed in vinegar arise from the action of the acid on the metallic vessels employed. Vinegar made by the *quick* process, or in *vinegar fields*, never contains any of these compounds, unless the vinegar is afterwards distilled in metallic vessels. At a high temperature, with access of air, acetic acid acts on the metallic parts of the still or condensing worm. As copper, lead, tin, and zinc, are generally the materials used in the construction of the still or worm, these are the only bodies that have to be looked for in the vinegar. A portion of the vinegar is submitted to a stream of sulphuretted hydrogen gas; if a black colour or precipitate be produced, copper or lead is present. Another portion (about 10 ozs.) of the vinegar is evaporated to dryness in a basin, and the residue heated to redness in a porcelain crucible, and the whitish ash remaining treated with a few drops of nitric acid, heated, and filtered; if, on treating the solution with ammonia, a more or less blue colour is given to the liquid, copper is present. Tin gives a yellow precipitate with sulphuretted hydrogen. If, on the addition of ammonia, or ammonium sulphide, a white precipitate is formed, zinc is present; if the precipitate is black, or has a greyish cast, there is likewise a small proportion of iron. The quantity of salts of these metals found in vinegar is generally so very small as to escape detection, unless a large quantity of the vinegar is evaporated, and the residue submitted to a thorough chemical examination.

Should pepper, chillies, &c., be added to vinegar for the purpose of conferring more pungency, they may be detected by neutralizing the acid with carbonate of soda, and tasting the liquor; if these bodies be present the solution will still retain the sharpness peculiar to such spices.

Flies (*musca cellaris*) and eels (*vibrio aceti*) are often found in vinegar; they may be destroyed by passing the vinegar through tubes immersed in boiling water.

The average percentage of fixed matter which remains after evaporating the different vinegars to dryness is as follows:

Wine Vinegar,	2·05 to 2·10
Beer Vinegar,	5·00 to 6·00
Cider Vinegar,	1·40 to 1·50

Vinegar is sometimes concentrated by exposing it to cold, and separating the layers of ice; although the greater part of the water is by this treatment removed, yet a large quantity of acetic acid is likewise abstracted, and where the vinegar is very dilute the process is not at all economical. Another method is, to keep the vinegar heated at a temperature between 212° and 220° Fahr. (100° to 104° C.); for while water boils at 212°, the hydrated acetic acid boils at 248° Fahr. (120° C.), so that at 212° a large proportion of water is driven off and very little acid; every disadvantage is removed when the boiling point of the vinegar is elevated. Stein recommends for this purpose the addition of common salt, in the proportion of 30 lbs. for every 100 lbs. of vinegar. The acid then distils over without loss, and is obtained much stronger than in the ordinary mode of distillation.

Some cautions may here be given with reference to the vessels in which vinegar is kept, as these often consist of metals. A painted vessel should never be used; the basis of nearly all pigments is white lead, which readily dissolves in acetic acid, forming sugar of lead—lead acetate; and many paints contain copper and other metallic salts, soluble in acetic acid, any of which may prove poisonous. Iron is easily attacked by acetic acid; and although the salt which is formed in the liquid—the iron acetate—is not injurious in small quantity, yet it communicates to food a disagreeable taste.

Common earthen vessels, glazed with oxide of lead—litharge, red lead—part of which is frequently uncombined with the body of the ware, should not be employed; for the acid would undoubtedly dissolve that portion of the oxide, and might even attack the well-burned porcelain itself, the more so if the acid be heated in the vessel. Salt-glazed stoneware, good English pottery, porcelain, glazed or enamelled iron, silver, and copper (if kept quite bright), may all be employed for boiling acetic acid or its preparations with safety.

The proof vinegar of the excise has a spec. grav. of 1·0085, and contains about 5 per cent. of acetic acid. In commerce this vinegar is represented by No. 24, from the fact that 24 grains of pure dry carbonate of soda are required to neutralize a fluid ounce. Weaker vinegars are represented by the Nos. 18, 20, 22, according to their strength; and, as in the foregoing instance, these figures equal the number of grains of carbonate of soda that will saturate a fluid ounce.

Acetic acid is extensively employed to preserve animal and vegetable substances from decay or putrefaction. Wood vinegar is preferable to other varieties, on account of essential oils which it contains in small quantities, and which render its antiseptic properties more active. The creasote of this acid confers a smoky taste on meats.

Acetic acid is also employed to a large extent in the arts, chiefly in calico-printing and dyeing. When required for these uses it is united to bases, with which it forms acetates, principally used as mordants. It is likewise used in the preparation of varnishes, for dissolving gums and albuminous bodies. Aromatic vinegar is used medicinally.

ALUMINIUM TRIACETATE.—*Neutral Acetate of Alumina, Sesquiacetate of Alumina, Red Liquor.* $Al_2^{vi}(C_2H_3O_2)_6$.—This salt has never been obtained in the dry state. It can be prepared by decomposing a concentrated solution of aluminium sulphate by a concentrated solution of lead acetate:—

$$Al_2^{vi}(SO_4)_3 + 3Pb(C_2H_3O_2)_2 = 3PbSO_4 + Al_2^{vi}(C_2H_3O_2)_6.$$

It is likewise obtained when recently precipitated aluminium hydrate is digested with strong acetic acid.

WALTER CRUM considers that no true triacetate exists, but that the solution contains aluminium diacetate with an equivalent of free acetic acid. In support of this view, he proves that when means are taken to evaporate the aluminous solution at a low temperature with sufficient rapidity a dry substance is obtained, which may be redissolved easily and entirely by water. This is the diacetate:—

$$Al_2^{vi}\left\{\begin{matrix}(C_2H_3O_2)_4\\O\end{matrix}\right. + 4H_2O.$$

If the triacetate solution is allowed to stand for a few days in the cold a white precipitate is formed, which contains five equivalents of water:—

$$Al_2^{vi}\left\{\begin{matrix}(C_2H_3O_2)_4\\O\end{matrix}\right. + 5H_2O.$$

This modification is insoluble in water, slightly soluble in weak acids, and very soluble in caustic alkalies.

If the solution of the neutral acetate is heated to 212° Fahr. (100° C.) another basic acetate is obtained, containing two equivalents of water and having the composition—

$$Al_2^{vi}\left\{\begin{matrix}(C_2H_3O_2)_4\\O\end{matrix}\right. + 2H_2O,$$

at the boiling temperature; the liquid is thus deprived in about half an hour of the whole of its alumina, which goes down with two-thirds of the acetic acid, leaving one-third in the liquid.

Soluble Diacetate with four Equivalents of Water.—Notwithstanding the tendency of a concentrated solution of aluminium triacetate to deposit the insoluble salt, it may be evaporated, with certain precautions, to a dry substance soluble in water. For this purpose it must be spread very thin over sheets of glass or of porcelain, and exposed to a heat not exceeding 100° Fahr. (38° C.); and as it runs together into drops, like water upon an oiled surface, it must be constantly rubbed with a platinum or silver spatula. If these precautions are neglected, a mixture is obtained of the insoluble with the soluble acetate. The soluble salt is thus produced in scales having the appearance of gum when moistened, and leaving no residue when dissolved in water.

Aluminium diacetate may be produced at once in solution, and is the most suitable combination from which to form dry soluble diacetate. CRUM'S mode of proceeding is as follows:—Dissolve 24 parts of precipitated aluminium diacetate in 15 of rectified sulphuric acid, and 40 of water. Dilute further with 100 parts of water, and add about 44 parts of lead carbonate to precipitate the sulphuric acid. Filter the solution, and pass sulphuretted hydrogen through it until it ceases to precipitate lead, and then add barium acetate so long as it is precipitated by the sulphuric acid of the lead sulphate which had remained in solution. When in this state, if the mixture be well agitated for half an hour in an open vessel, the excess of sulphuretted hydrogen will be removed, and it may be filtered without the danger of the filtrate becoming afterwards milky. A solution is thus obtained containing about 4 per cent. of aluminium diacetate, which is the strongest solution even of this modification which can be preserved for any length of time without depositing an insoluble salt. Spread thinly over sheets of glass it evaporates at 60° to 100° Fahr. (15° to 38° C.) without running into drops as does the triacetate solution. The scales which it forms are transparent and soluble in water. The solution of diacetate has no smell of acetic acid at ordinary temperatures. Its formula is—

$$Al_2^{vi}\left\{\begin{matrix}(C_2H_3O_2)_4\\O\end{matrix}\right. + 4H_2O;$$

or in equivalents—

$$(Al_2O_3 2\bar{A} + 4Aq).$$

Insoluble Diacetate with five Equivalents of Water.—Triacetate solution is produced by mixing together strong solutions of aluminium sulphate and lead acetate (as already described). The solutions are poured slowly together in a vessel surrounded with cold water, and much agitated to reduce the temperature, and filtered when cold. Any lead remaining in solution is precipitated by sulphuretted hydrogen, sulphuric acid by barium acetate. The strongest solution formed in this way contains about 5 per cent. of alumina (from about 6 lbs. of lead acetate in an imperial gallon of the mixture). This solution is left at rest for four or five days, when it begins, without losing much of its transparency, to deposit a crust which continues to increase in thickness. When the liquid is poured off and the crust allowed to dry, it separates readily from the vessel in hard plates like porcelain. If the solution be not left strictly at rest, it becomes turbid after some days, and the crust is produced in a more friable state. In cold weather this solution remains unaltered for a much longer time. Heated to redness, the salt becomes black from the decomposition of part of its acetic acid, and in this state it very slightly affects the colour of moistened litmus paper. Its analysis agrees with the formula—

$$\mathrm{Al}_2^{\mathrm{vi}}\left\{\begin{matrix}(C_2H_3O_2)_4\\ O\end{matrix}\right. + 5H_2O\,;$$

or in equivalents—

$$(Al_2O_3 2\bar{A} + 5\ Aq).$$

Insoluble Diacetate with two Equivalents of Water.—If heat be applied to the strong solution of aluminium triacetate described above, it speedily becomes turbid and deposits a white heavy powder, which falls readily to the bottom of the vessel. In a couple of days at 100° Fahr. (38° C.), a considerable quantity of this powder is deposited; but in two or three hours at 160° Fahr. (71° C.), and in a much shorter time at boiling heat, the whole of the salt is thrown down, and nothing remains in the liquid but acetic acid and a trace of alumina. The precipitate has a crystalline shining appearance in the moist state, and seems under the microscope to consist of small oval particles of uniform size. It falls into fine powder on drying, after which when mixed with water it remains a long time in suspension.

When heat is applied to a solution of triacetate containing only 3 per cent. of alumina it yields the insoluble diacetate; but in that case not acetic acid only, but a considerable quantity of aluminium acetate also, remains in solution. Solutions containing 2 per cent. of alumina are precipitated by boiling, if they have been kept for some weeks, but not if recently prepared.

In whatever way deposited this substance is exceedingly insoluble in acetic acid. It dissolves in sulphuric, hydrochloric, or nitric acid, forming aluminium salts and liberating acetic acid. Analysis gives results agreeing with the formula—

$$\mathrm{Al}_2^{\mathrm{vi}}\left\{\begin{matrix}(C_2H_3O_2)_4\\ O\end{matrix}\right. + 2\ H_2O$$

Red Liquor.—A solution of aluminium triacetate (or diacetate, plus one equivalent of acetic acid) extensively used as a mordant liquor by calico-printers. So highly esteemed is aluminium acetate for forming dense opaque lakes, that one-fourth of the total quantity of alum manufactured in this country is utilized in this manner.

Sesquiacetate of alumina, as it is termed commercially—technically *red liquor*, from its being coloured with lichens—is always met with in the liquid state. It is manufactured for the use of calico-printers by adding to every gallon of calcium acetate liquor 2¾ lbs. of alum, agitating the mixture briskly, and then leaving it to rest, in order that the calcium sulphate may settle down. The decomposition of the calcium acetate is known by testing a small portion of the filtered liquid in a tube with a concentrated solution of alum; if a precipitate of calcium sulphate falls more alum must be added, till the acetate of lime is completely decomposed. The liquor is next filtered off, and the solution concentrated by evaporation till it acquires a spec. grav. of 1·087 to 1·100; allowed to repose for some time to deposit any sulphate of lime, and then drawn off for use or for market. The quality of this liquid as a mordant is inferior to that next described, on account of the imperfect decomposition of the lime salt, and the presence of a small portion of lime still retained in the red liquor, which impairs very much the beauty and gloss of the colour given to the cloth.

A better mordant is made by decomposing alum by lead acetate. Since lead sulphate is insoluble, the decomposition of the alum solution is more perfect than when it is acted upon by acetate of lime; nevertheless, *red liquor* is not a true acetate, but a mixture of aluminium acetate, sulphate, and hydrate, with potassium sulphate, as will be seen from the recipes in general use for its manufacture. In practice, in place of using quantities equivalent to the production of aluminium triacetates, it is found advantageous to employ equal parts of alum and sugar of lead, or even a rather less quantity of the latter. The alum is dissolved in boiling water, and the powdered lead acetate added to the solution. About one-tenth of crystallized carbonate of soda, or a little carbonate of lime, is added to the alum, to combine with the free acid. The three following recipes serve to indicate the proportions employed:—

No. 1.—Dissolve 100 lbs. of alum in 50 galls. of boiling water, and add 100 lbs. of acetate of lead in fine powder, stirring the mixture well at first, and likewise several times during the cooling.

The clear supernatant liquid consists of an aluminium diacetate, potassium sulphate, and a little basic aluminic sulphate.

No. 2.—Dissolve 100 lbs. of alum in 50 galls. of water; to the solution add slowly 10 lbs. of crystallized carbonate of soda, and then stir in 100 lbs. of acetate of lead in powder.

No. 3.—Dissolve 100 lbs. of alum in 50 galls. of boiling water, and add in small portions 6 lbs. of crystallized carbonate of soda, and then stir in 50 lbs. of acetate of lead in powder, as before.

Nos. 2 and 3 contain acid aluminium diacetate, basic aluminic sulphate dissolved in acetic acid, and potassium and sodium sulphates. No. 2 becomes cloudy at 154° Fahr., and gelatinizes at 165° (68° and 74° C.);

No. 3 clouds at 175°, and gelatinizes at 192° (80°, 89° C.); the cloudiness disappears on cooling, and is entirely prevented by an excess of alumina in the solutions. According to the experiments of KÖCHLIN SCHONCH, it appears that the activity of the red liquor is not wholly dependent upon the amount of aluminium acetate which it contains, since a portion of the salt is converted into a basic sulphate which combines with the triacetate and constitutes the true mordant.

When used by the calico-printer the red liquor is thickened with gum or some other suitable material, and with it the design is impressed upon the cloth by a wood block, or by any other means; on subsequently submitting the goods to the drying-bath, acetic acid is partly volatilized, and the aluminous basic compound remains perfectly combined with the cloth.

It is immaterial, as to the effect on the texture, and the beauty of colour produced on the cloth, whether 100 lbs. of alum be decomposed by 125 or 75 lbs. of acetate of lead, since the aluminium acetate acts by giving up its base to the fibre of the cloth, and this is effected as well when a basic sulphate of the earth is present as when it is wholly in the form of a sesquiacetate. RUNGE differs from this view; by his experiments he endeavours to show that the quantity of acetate of lead should be always 120 lbs. to every 100 lbs. of alum, and that even the amount of water employed affects the quality of the product. He based equal weights of cotton fabric in each of the following solutions, made by adding—

100 lbs. of alum,
75 lbs. of acetate of lead, and
280 lbs. of water together, agitating the mixture, and filtering :

Secondly, by dissolving—

100 lbs. of alum in
448 lbs. of water, and adding
120 lbs. of acetate of lead in powder, agitating the mixture, and filtering off the clear liquor as above.

The fabrics being allowed to remain in an equal measure of these solutions for the same time, and dried at the same temperature, were washed with equal quantities of hot water; the washings from the cloth mordanted in the first solution contained much alumina, while only very slight traces were indicated by the washings from the cloth steeped in the second solution. He did not, however, take into account the neutralization of a part of the sulphuric acid by carbonate of soda, which, by bringing basic salts into action, materially changes the reaction which takes place during drying, and undoubtedly fixes a much larger amount of alumina in the fabric than would otherwise be the case. And although a portion of this alumina may be washed out after drying, it is questionable whether the advantage of using so large a proportion of lead acetate is not counterbalanced by the greatly increased cost. The usual addition of carbonate of soda, to the extent of about one-tenth of the alum employed, acts advantageously in the manufacture of red liquor, when a low proportion of sugar of lead is used, by uniting partly with the sulphuric acid, and producing a basic sulphate, as well as acetate of alumina, as mentioned above.

CRACE CALVERT states, from practical observations, that a sulphacetate of alumina is to be preferred, as giving the most satisfactory results. He considers that a mordant of such a composition is the best adapted for fixing the colours, on account of the excess of alumina in such a solution, above those which contain, besides the aluminous salts, salts of the alkalies, which are inert in the uses for which red liquor is manufactured.

The preceding he prepares by mixing together—

453 lbs. of ammonia alum,
379 lbs. of lead acetate, and
1132 lbs. of water;

or,

383 lbs. of aluminium sulphate,
379 lbs. of lead acetate, and
1132 lbs. of water;

or,

453 lbs. of alum, and a quantity of solution of acetate of lime, amounting to 158 lbs.;

or,

333 lbs. of aluminium sulphate, with the same amount of acetate of lime solution.

On agitating the foregoing mixtures, decomposition takes place; sulphate of lead or of lime is thrown down, and a sulphacetate remains, with an equivalent of ammonium sulphate from the ammonia alum. Instead of alum, many printers now use aluminium sulphate—

$$Al_2^{vi}(SO_4)_3 + 18H_2O;$$

or,

$$Al_2O_3 3SO_3 + 18H_2O;$$

in the fabrication of this mordant, which is much more economical, as the solution of this salt, brought to the standard strength, or 1·085 spec. grav., contains more alumina than the ordinary red liquor of that strength, as the following analyses show :—

	Formula. $Al_2^{vi}SO_4,4C_2H_3O_2 + (NH_4)_2SO_4$.		Formula. $Al_2^{vi}SO_4 2C_2H_3O_2 + (NH_4)_2SO_4$.	Formula. $Al_2^{vi}SO_4,4C_2H_3O_2$.
	Mordant A.	Mordant B.	Mordant C.	Mordant D.
	Grs. Oz. Grs.	Grs. Oz. Grs.	Grs. Oz. Grs.	Grs. Oz. Grs.
Alumina,	1680·0 = 3 368	1830·0 = 4 80	1239·0 = 2 365	2164·4 = 4 414
Acetic acid,	3369·8 = 7 307	3570·0 = 8 170	1281·7 = 2 406	3679·2 = 8 179
Sulphuric acid,	2642·5 = 6 17	2800 0 = 6 175	3017·0 = 6 392	1664·6 = 3 352
Ammonia and water,	674·1 = 1 236	910·0 = 2 35	653·1 = 1 215	

In 1872 Messrs. STORCK & Co., of Asnières, France, patented a process for the manufacture of aluminium acetate from the phosphate. Aluminium phosphate is converted into acid phosphate by dissolving it in phosphoric acid. To this liquor sufficient lead acetate is added to precipitate the whole of the phosphoric acid. Soluble aluminium acetate and insoluble lead sulphate are thus formed. The aluminium acetate is then separated by filtration, and subsequently treated in a similar manner to that obtained for industrial purposes by the double decomposition with aluminium sulphate. The phosphate of lead is either used to produce pure phosphoric acid by decomposing it by sulphuric acid or sulphuretted hydrogen, or an alkaline phosphate is formed thereof by treating it with an alkaline sulphide. It may likewise be used for the production of phosphorus; in this case it is mixed with charcoal and subjected to distillation.

AMMONIUM ACETATE, *Liquor Ammoniæ Acetatis* or *Spiritus Mindereri*, Pharmacopœia; *Neutral Acetate of Ammonia*, $NH_4,C_2H_3O_2$.—This substance is a white inodorous salt. It is obtained by saturating glacial acetic acid with dry ammonia gas. It is very difficult to obtain in the crystalline form, on account of its aqueous solution giving off ammonia when evaporated, thus becoming converted into the acid salt. When heated it evolves first ammonia, then acetic acid, and lastly acetamide (C_2H_5NO). It melts at 192° Fahr. (89° C.); inclosed over oil of vitriol it loses 9 per cent. of its weight and becomes transformed into the acid salt.

In medicine it has long been used as a diaphoretic.

It was formerly obtained by saturating distilled vinegar with carbonate of ammonia. The method now adopted is to reduce carbonate of ammonia to powder, and add it gradually to acetic acid until a neutral solution is formed. The proportions used are—acetic acid, 10 fluid ounces; ammonium carbonate, 3½ ounces (or a sufficiency); then add 2½ pints of distilled water.

Ammonium Acid Acetate, Diacetate, $NH_4C_2H_3O_2,C_2H_4O_2$.—When equal weights of ammonium chloride and potassium acetate are distilled together at a moderate temperature, ammonia is at first eliminated; and afterwards ammonium diacetate distils over in the form of an oily liquid, which concretes into acicular crystals, which are deliquescent, and are dissolved in all proportions by water and alcohol.

$$\overset{\text{Ammonium chloride.}}{2NH_4Cl} + \overset{\text{Potassium acetate.}}{2KC_2H_3O_2} = \overset{\text{Ammonia.}}{NH_4O} + \overset{\text{Ammonium diacetate.}}{NH_4,C_2H_3O_2,C_2H_4O_2} + \overset{\text{Potassium chloride.}}{2KCl.}$$

Dry ammonia, transmitted into the fused diacetate, converts it into the solid neutral acetate—

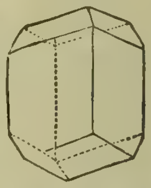
$$\overset{\text{Diacetate.}}{NH_4C_2H_3O_2,C_2H_4O_2} + \overset{\text{Ammonia gas.}}{NH_3} = \overset{\text{Neutral acetate,}}{2NH_4C_2H_3O_2.}$$

Diacetate of ammonia forms striated prisms, fusible at 168° Fahr. (76° C.), and subliming unchanged at 248° Fahr. (121° C.).

ACETATES OF COPPER. *Cuprous Acetate*, $Cu_2(C_2H_3O_2)_2$.—This salt is produced by the action of heat upon cupric acetate (verdigris, described below). It is a white substance crystallizing in fine needles; it is decomposed by water into cupric acetate and yellow cuprous hydrate. It reddens litmus, and has a caustic astringent taste. According to BERZELIUS this body is contained in common green verdigris, and sublimes when that substance is distilled.

Normal Cupric Acetate, Crystallized Verdigris; Verdet, Cristaux de Venus, French; $Cu(C_2H_3O_2)_2$.—The normal acetate of copper is formed by dissolving the cupric oxide, or common verdigris, in acetic acid, or by precipitating a solution of sulphate of copper by normal acetate of lead or baryta, filtering off the precipitated sulphate of lead or baryta, and evaporating the filtered liquid, and crystallizing. In each case the liquor must be highly concentrated and left in a cool place.

Fig. 33.



The crystals are dark bluish prisms (Fig. 33), belonging to the monoclinal system, and containing $Cu(C_2H_3O_2)_2 + H_2O$. This salt is efflorescent, soluble in about 13½ parts of cold, and 5 of boiling water, possesses a disagreeable metallic taste, and is poisonous like all soluble copper salts. The crystals, after drying in vacuo, lose no more water at 212° Fahr. (100° C.), but give off 9 per cent. of their water between 230° Fahr. (110° C.), and 284° Fahr. (140° C.). Between 496° Fahr. (240° C.) and 532° Fahr. (260° C.) glacial acetic acid is given off. When heated strongly in the air crystals of verdigris take fire and burn with a vivid green flame.

Acetate of copper was formerly employed in the manufacture of acetic acid. Cuprous oxide (Cu_2O) is obtained in red octahedral crystals when the neutral salt is heated with organic substances, such as sugar, honey, starch, &c.

When commercial verdigris is dissolved in dilute acetic acid, and the salt crystallized at 40° to 45° Fahr. (5° to 8° C.), an acetate with five atoms of water is obtained, in beautiful blue oblique four-sided prisms.

$$Cu(C_2H_3O_2)_2 + 5H_2O.$$

On raising the temperature to about 86° Fahr. (30° C.), the crystals almost instantaneously lose their blue colour, and acquire a greenish hue; four atoms of water are expelled, and neutral acetate remains, with one atom of water.

Its chief use in the arts is in making pigments, and for resisting the blue colour which the indigo would communicate in the indigo-bath of the calico-printer. In the latter case, its mode of action depends on the readiness with which it parts with oxygen, whereby the indigo is oxidized before it can exert any action on the cloth, being itself reduced to the state of acetate of suboxide of copper. Crystallized verdigris is occasionally employed as a transparent green water-colour or wash for tinting maps. In medicine it is used for external application.

VERDIGRIS.—*Ærugo; vert-de-gris*, French; *grün span*, German. A mixture of the basic cupric acetates. These are three in number:—

Sesquibasic, ...	$(Cu(C_2H_3O_2)_2)_2CuO + 6H_2O$
Dibasic, ...	$Cu(C_2H_3O_2)_2CuO + 6H_2O$
Tribasic, ...	$Cu(C_2H_3O_2)_22CuO + 3H_2O$

Sesquibasic cupric acetate is found in all the verdigris of commerce. It is prepared by lixiviating common verdigris with tepid water, and leaving the filtrate to evaporate spontaneously. It is obtained more nearly pure by adding ammonia, little by little, to a boiling concentrated solution of the normal acetate, until the precipitate which is at first formed is redissolved. The new salt then crystallizes out as the liquor cools. The crystals are in pale blue scales; at 212° Fahr. (100° C.) they lose 10·8 per cent. of their water. Their aqueous solution is decomposed by boiling, acetic acid being given off, and the black oxide of copper precipitated.

According to BERZELIUS, green verdigris is a mixture of this salt with small quantities of all the other acetates of copper.

Dibasic cupric acetate constitutes the greater part of the blue variety of verdigris manufactured at Montpellier and other places in the south of France. It forms beautiful, delicate, silky, blue, crystalline needles and scales, which, when ground, form a fine blue powder. When heated to 140° Fahr. (60° C.) they lose 23·45 per cent. of water, and become transformed into a beautiful green, a mixture composed of the neutral and tribasic acetates.

Dibasic Cupric Acetate. Normal Acetate Tribasic Cupric Acetate.

$$2Cu(C_2H_3O_2)_2CuO = Cu(C_2H_3O_2)_2 + Cu(C_2H_3O_2)_2 2CuO.$$

By repeated exhaustion with water the dibasic is resolved into the insoluble tribasic salt, and a solution of the normal and sesquibasic cupric acetates.

Tribasic cupric acetate is the most stable of any of the acetates of copper. It is prepared by boiling the aqueous solution of the neutral acetate, by heating it with alcohol, by digesting its aqueous solution with cupric hydrate, or by exhausting blue verdigris with water, as just mentioned. The first methods yield the salt in the form of a bluish powder composed of needles and scales; the last as a bright green powder. This salt gives off all its water at 352° Fahr. (160° C.); at a higher temperature it decomposes and evolves acetic acid. Boiling water decomposes the solid tribasic acetate into a brown mixture of the same salt with cupric oxide.

Blue Verdigris.—This salt is formed for commercial purposes by exposing thin copper plates in a confined space, to the combined action of air and moisture, or by submitting copper plates to the action of fermenting refuse from the wine factories (technically *marcs*); in the course of a few days a coating, consisting for the most part of dibasic cupric acetate, forms on the plates, which may be scraped off, and the remaining part of the plate submitted to a fresh operation, till all the copper is converted into verdigris.

The manufacture of verdigris on the large scale is conducted as follows:—In France the chief seats of this manufacture are at Grenoble and Montpellier, where the operations are conducted in a rude but effective way, and usually by women. Husks and refuse of grapes from the wine factories, not entirely exhausted of their juice, are spread loosely in casks until the acetous fermentation takes place. The casks or vessels are covered with matting to protect them from dirt. The limit to which fermentation of the "marcs" should be carried, is known by introducing a test sheet of copper into the mass for twenty-four hours; if, on withdrawing it at the end of that time, it is found covered with a uniform green coating, the proper degree of fermentation is reached, otherwise the mass is allowed to remain a day or two longer. Alternate layers of sheets of copper of $\frac{1}{24}$th of an inch thick, and the fermented marcs are introduced into large casks, observing that the top and bottom layers are of the latter.

Sheets of copper are prepared by hammering bars of the metal to the above thickness—the more compact the copper sheets the better—and they are then cut out into pieces of 6 or 8 inches long by 3 to 4 broad. These plates are immersed in a concentrated solution of the verdigris, and dried over a charcoal fire; then heated to about 200° Fahr., being held by a cloth in the hand, and packed in the vessels with layers of the fermented husks, as above-mentioned. If the plates be not immersed in the solution of the acetate before packing in the casks with the fermented stalks and skins of the grape, they are liable to be covered with a black coating instead of the green acetate. The quantity of metal required to fill each vessel is between 30 and 40 lbs. Twenty days are sufficient to complete the corrosion of the copper sheets, and induce their combination with the acetic acid present in the marcs, but often sixteen or twelve days perfect the work. After this period the upper layer of marcs will appear whitish, and if the whole has worked favourably the plates will be covered with silky crystals of a green colour. The plates are then taken from the casks, and dried in the air for two or three days, after which they are moistened with water and again placed to dry, by laying them upright against each other for a week. This process of moistening with water is continued at regular intervals of a week for six or eight times. By this mode of operation the plates swell and become encrusted with increasing coatings of the copper salt, which are detached from the remainder of the plates by a copper knife. The scraped plates are submitted to a fresh treatment, till the whole of the copper is converted into verdigris. After scraping off the salt it is made into a thick consistent mass by kneading it with a little water, and in this state it is packed into leathern bags, which are placed in the sun to dry, until the mass hardens and forms the tough substance which constitutes the commercial article.

Green Verdigris.—At Grenoble the process is nearly the same as above, excepting that, instead of moistening the plates with acetous liquors, acetic acid is employed. In Germany, Sweden, and England, woollen cloths steeped in pyroligneous acid are used, which are placed alternately with the copper plates in a square wooden box. The cloths are moistened with pyroligneous acid every three days for twelve or fifteen days, when small crystals begin to form on the plates. So soon as this happens the cloths are partly withdrawn, and a space allowed for the circulation of the air, the whole being moistened weekly with water. Generally five or six weeks elapse before the completion of the work.

Cupric acetates are likewise made by acting upon thin sheets of copper, in small vessels, with acetic acid. The copper is not immersed in the acid, but suspended over it, so as nearly to touch its surface; a temperature of about 150° to 180° Fahr. (66° to 83° C.) is maintained during the operation. The plates become in time coated with acetate, which is scraped off and dried for the market, as in the forementioned processes.

The composition of blue verdigris, according to Berzelius and Phillips, is:—

	Dibasic Acetate calculated.	Berzelius.	Phillips.		
			French Verdigris.	English	
				Crystallized.	Compressed
Cupric Oxide, ...	43·24	43·34	43·50	43·25	44·25
Anhydrous Acetic Acid,	27·57	27·45	29·30	28·30	29·62
Water, ...	29·19	29·21	25·20	28·45	25·51
Impurities, ...	..	..	2·00	..	0·62
	100·00	100·00	100·00	100·00	100·00

This salt is employed in calico printing for precisely the same purpose as the neutral acetate, namely, as a resist paste in the indigo dye bath. All the acetates of copper are used for painting in oil. In medicine they are employed as escharotics. They are very poisonous; their manufacture, however, does not appear to be productive of inconvenience to the workpeople engaged.

Good verdigris should be dry, have a fine bluish-green colour, and be soluble in dilute acetic and sulphuric acids, and also in ammonia.

Verdigris is often adulterated, generally with finely ground pumice, chalk, and sulphate of copper. The purchasers acquainted with this article judge of the relative purity of the sample from its bright colour, and by kneading it on the palm of the hand with a little water; by the latter test the presence of sand is detected, as the acetates when alone form a paste free from any grittiness.

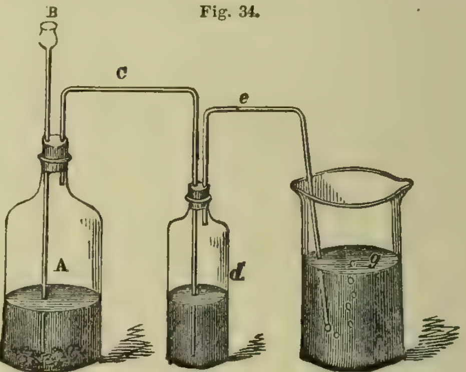
For the detection of chalk—carbonate of lime—a weighed portion of the verdigris, in powder, is introduced into a flask, and hydrochloric acid poured upon it; if effervescence takes place, it indicates the presence of carbonates; should, however, no effervescence occur, and at the same time a residue of silica remains undissolved, it shows that pumice, or some analogous body, is the adulterant. The residue is greater or less in proportion to the extent of adulteration.

If the hydrochloric acid solution of the above be filtered off, and the residue, being well washed, dried in a water-bath at 212° Fahr. (100° C.), and afterwards burned in a weighed platinum crucible till the whole of the charcoal of the paper is consumed, and weighed—the increase of weight will give the amount of insoluble impurities in the sample.

Sulphates of copper or iron are detected by adding barium chloride to the filtered liquid and washings; if either of these is present, a white insoluble precipitate of barium sulphate will fall down. By placing the beaker on a hot sand-bath the precipitate quickly settles down, after which it is filtered off, washed with boiling-hot water as long as any barium chloride is extracted, and then placed in a water or air-bath to dry: the precipitate is next detached from the filter upon a sheet of clean dry glazed paper; the filter is burned alone in the platinum crucible till the ashes contain no charcoal from the paper; the precipitate is then introduced, heated to redness, and when cold weighed.

The amount of the chalk or other lime compound may be ascertained by weighing out 100 grains, and dissolving them in a beaker-glass with hydrochloric acid; the clear solution is then filtered off from the residue, and a current of sulphuretted hydrogen passed through the liquid, till the whole of the copper is thrown down in the form of a brownish-black precipitate. The sulphuretted hydrogen—sulphydric acid—is generated in an appparatus like the annexed Fig. 34:—A is a bottle containing pieces of iron sulphide, and a few ounces of water; through the cork two tubes pass; the funnelled one, B, reaches to the bottom, and the other, C, opens at a quarter of an inch below the cork, which should fit the bottle air-tight. The sulphuretted hydrogen is generated by pouring through the funnel tube, B, some strong sulphuric acid, which reacts on the iron sulphide, giving rise to the gas, which passes off by the tube, C, bent at right angles, the longer limb passing through the cork of the bottle, *d*, which contains some distilled water, for the purpose of washing the gas. A second tube, *e*, bent at right angles, conveys the gas to the beaker-glass, *g*, containing the solution, from which the substance is to be precipitated.

Fig. 34.



The subjoined equation exhibits the decomposition:—

Iron sulphide.		Sulphuric acid.		Iron sulphate.		Hydrogen sulphide.
FeS	+	H_2SO_4	=	$FeSO_4$	+	H_2S.

When the whole of the copper has been precipitated as sulphide, it is filtered off, washed with water, and the washings added to the filtrate. Ammonia, in slight excess, is poured into the solution, and then ammonium oxalate, and the beaker-glass placed on the sand-bath. When the lime oxalate has subsided, it is collected, washed with water, dried as the preceding precipitates, and burned in a platinum crucible. The ignition should be gentle, and at a heat very little above dull redness, so as not to expel carbonic acid from the carbonate of lime, which is formed by the action of the heat on the lime oxalate, as is shown in the annexed decomposition:—

$$\overset{\text{Calcium oxalate.}}{CaC_2O_4} = \overset{\text{Calcium carbonate.}}{CaCO_3} + \overset{\text{Carbonic oxide.}}{CO}$$

The weight of the carbonate of lime obtained is equal to the amount of that adulterant which has been added to the verdigris.

Verdigris generally contains about 3 per cent. of impurities. Sometimes the insoluble matter in it is 6 per cent.; in such a case, however, the article is of inferior quality.

Formerly the manufacture of verdigris was one of the most lucrative in Belgium, and it was also carried on profitably in France; but at the present time the production of this substance is not confined to those countries. France still produces considerable quantities of the article, and nearly the whole of the salt imported into this kingdom is from that country. Until the 19th of March, 1845, the duty on verdigris imported into this country was $1\frac{1}{20}$d. per lb. weight; it was then subjected to an *ad valorem* duty of 10 per cent., which was repealed in 1853. The imports are nevertheless small, as large quantities of verdigris are prepared in England with pyroligneous acid and cider refuse.

IRON ACETATES.—There are two acetates of iron, ferrous acetate and ferric acetate.

Ferrous Acetate, $Fe(C_2H_3O_2)_2$.—This salt may be prepared by dissolving either iron sulphide or metallic iron (generally iron turnings are used) in strong acetic acid; in the former case sulphuretted hydrogen, in the latter gaseous hydrogen, is evolved.

$$\overset{\text{Ferrous sulphide.}}{FeS} + \overset{\text{Acetic acid.}}{2C_2H_4O_2} = \overset{\text{Ferrous acetate.}}{Fe(C_2H_3O_2)_2} + \overset{\text{Sulphydric acid.}}{H_2S.}$$

$$Fe + \overset{\text{Acetic acid.}}{2C_2H_4O_2} = \overset{\text{Ferrous acetate.}}{Fe(C_2H_3O_2)_2} + 2H.$$

On concentrating the solution, small colourless silky prismatic needles are obtained, which are very soluble in water, and which, when exposed to the air, rapidly absorb oxygen, and become converted into ferric acetate. This compound may likewise be obtained by decomposing a solution of the ferrous sulphate (green vitriol, $FeSO_4$) by calcium or lead acetate: 1615 parts of ferrous sulphate require 2575 parts of lead acetate, or 999 parts of calcium acetate; but in this method a greater or less amount of ferric acetate is also formed, which can, however, be reduced to the state of ferrous acetate by passing a stream of sulphuretted hydrogen gas through the liquid.

The avidity with which this substance absorbs oxygen renders it of great value as a reducing agent.

For commercial purposes this compound is manufactured as follows:—Into a large cast-iron boiler or pot a quantity of iron turnings, hoops, or nails are introduced, and acetic acid—the crude pyroligneous acid from the distillation of wood—is poured in upon them. The strength of the acid is generally of 7° Twaddle, or spec. grav. 1·035. A temperature of 150° Fahr. (66° C.) is maintained till the solution of ferrous acetate is obtained, of a spec. grav. 1·09, or 18° T., at 60° Fahr. (15° C.). During the solution of the iron much tarry matter separates, which is skimmed off, and the solution frequently agitated, to free it as much as possible from the tar. As soon as the above strength is gained the solution is allowed to cool, for a further quantity of impurities to separate. When clean turnings are operated upon, the process of solution is completed in five to seven days. The hydrogen that is eliminated during the solution of the iron prevents the oxidation of the iron salt, as is seen in the equation already given. Were any ferric acetate formed, the hydrogen, by combining with part of its oxygen, would again reconvert it to ferrous acetate.

Some printers dissolve the iron without the aid of heat, but this method is slow and unsatisfactory, for the deposit of tarry bodies on the iron prevents the action of the acetic acid; besides, from the long exposure to the air, some sesquisalt of iron is generated. The usual produce from 100 gallons of acetic acid, and a proportionate quantity of iron turnings, is 60 to 70 gallons of acetate of iron, spec. grav. 1·090, or 18° T.; and when this solution is reduced by the addition of water to a spec. grav. 1·060, it produces with madder a deep black.

The mordant is likewise made by decomposing a solution of sulphate of iron ($FeSO_4$) by acetate of lime; the proportions employed are the following:—

400 lbs. of sulphate of iron—copperas—dissolved in
100 gallons of hot water, and the solution decomposed in
75 gallons of acetate of lime liquor, spec. grav. 1·08.

On agitating the mixture, the decomposition is rendered complete; the clear liquor, which is siphoned off after subsidence of the sulphate of lime, possesses a density of 1·110.

When the liquor is not required for immediate use it becomes oxidized, and deposits ferric acetate; to prevent this some metallic iron is left in contact with the solution. Sometimes, when a large quantity of pyroligneous matters deposits in the solution, the iron is prevented from acting by becoming coated with these substances; in such instances the formation of the basic acetate may be prevented by suspending fine iron wire in the liquid.

In some of the continental factories the ferrous acetate is manufactured by decomposing the carbonate of iron (ferrous carbonate, $FeCO_3$) with lead acetate: lead carbonate precipitates, and the blackish supernatant liquor is the acetate of iron in a very pure state. It is kept from oxidizing by immersing in it some bright iron filings. The lead-salt formed repays the cost of the manufacture of the acetate.

Both ferrous and ferric acetates are precipitated by sulphuretted hydrogen.

Ferric Acetates.—*Neutral Ferric Acetate; Sesquiacetate of Iron*, $Fe^{vi}_2(C_2H_3O_2)_6$.—This salt may be obtained in the pure state by decomposing a solution of lead acetate by addition of ferric sulphate ($Fe^{vi}_2(SO_4)_3$) in slight excess. In the course of twenty-four hours the excess of ferric sulphate precipitates as a basic salt. It is also produced, though more slowly, by dissolving ferric hydrate or ferric carbonate, obtained by precipitation, in strong acetic acid. This method occupies more time, but affords better guarantees for the purity of the compound. For ordinary purposes it may be made by mixing solutions of ferric sulphate and calcium or barium acetate in an iron vessel, and agitating the liquid.

The acetate thus obtained by the use of cold liquors is wine-red in colour, and presents all the characteristics of solutions of ferric salts. It is uncrystallizable, and on evaporation yields a deliquescent gelatinous paste. It is also soluble in alcohol.

When a solution of ferric acetate is brought nearly to the boiling point its colour becomes four or five times more intense, and it evolves a distinct odour of acetic acid, without, however, producing any precipitate. The salt has nevertheless become more basic, and addition of any soluble sulphate, or even of free sulphuric acid, immediately precipitates the whole of the iron as ferrous sulphate ($FeSO_4$). After cooling, this basic acetate is stable even in presence of excess of acid, for it retains its colour, and can be precipitated by sulphuric acid at the end of several hours. If the solution is allowed to rest for a few days neutral acetate, with its usual characteristics, is regenerated.

When a solution of ferric acetate is boiled rapidly it disengages acetic acid vapours, and in about half an hour's time begins to separate its iron in the state of hydrate (probably $Fe_2O_3,2H_2O$).

If in place of boiling the solution in an open vessel, it is heated in a closed vessel placed in a water bath to 212° Fahr. (100° C.) for a few hours, it undergoes a very remarkable change. Its colour becomes, little by little, of a brighter red colour, without losing in intensity; seen by reflected light it appears opaque and opalescent, but appears perfectly clear and limpid when viewed by reflected light, even when examined under the microscope. It has also lost the metallic taste peculiar to salts of iron, and rather resembles vinegar in its flavour. If the exposure in the water bath has been sufficiently prolonged, addition of potassium ferrocyanide produces no precipitate, nor does the sulphocyanide augment its red colour. A trace of sulphuric acid or any alkaline salt suffices to precipitate the whole of the iron in solution as a ferric hydrate of a red colour, and totally insoluble in all acids in the cold. Nitric and hydrochloric acids, when concentrated, precipitate ferric hydrate in the form of a granular brown powder, which dissolves completely in cold water, reproducing a solution, red in colour, and transparent to transmitted, but opaque to reflected light. This peculiar characteristic of the brick-red liquor just described is held by Péan de Saint Gilles, who first observed the phenomena, to be due, not to a chemical, but to a purely mechanical action exercised by the acetic acid upon the ferric hydrate; separating its insoluble particles to the minutest state of division, and thus simulating a true solution. Many chemists explain in this manner the apparent solution of Prussian blue in oxalic acid.

Solution of ferric acetate is much used as a mordant by dyers; like the acetate of alumina, it deposits an insoluble basic salt when heated, and hence its utility in dyeing operations.

Triferric diacetate—$Fe^{vi}_2\left\{\begin{matrix}(C_2H_3O_2)_2\\(H_2O)_4\end{matrix}\right\}2Fe_2O_3$—is an insoluble yellow powder, precipitating from ferrous acetate which has oxidized in the air, and even out of the neutral ferric acetate when kept for some time, especially if an alkaline salt be present.

Sesquiacetate of iron is manufactured chiefly for the use of dyers, the salt being rarely employed by the calico-printer.

Where the dyer requires uniform grounds, he cannot well employ ferrous salts, for when cotton is impregnated with such a solution as copperas or the ferrous acetate, it attracts oxygen from the air while drying; and the sesquioxide of iron, or a basic salt, collects in those parts not yet dry, and will, of course, produce darker spots in those places when the cloth goes in the dye-bath. It is therefore better to prepare a ferric acetate at once, either by pouring acetic acid repeatedly over iron turnings for several weeks, in vessels exposed freely to the air, or, what is still better, by double decomposition of a ferric salt with lead acetate or lime acetate.

A recipe for this purpose states:—Dissolve 1 lb. of iron-alum in half a gallon of water, add 1 lb. of acetate of lead, stir the liquor well, let it settle, and decant or filter. The solution made from iron-alum will not keep long, as it gradually deposits an insoluble basic salt from the presence of potassium sulphate, while that made from ferric sulphate will retain its properties for a great length of time; but on the other hand, iron-alum is more convenient to use, from its containing known quantities of ferric oxide. The difficulty above-mentioned may be obviated by preparing only so much solution as is required for immediate use.

Ferric acetate may also be made from ferric sulphate and lead acetate. As the ferric sulphate is not so uniform in composition as iron-alum, it may be well to ascertain how much oxide of iron and sulphuric acid it contains, in order to know what quantity of lead acetate to employ in its decomposition. For this purpose weigh out 100 grains; dissolve in water, and filter; add 285 grains crystallized acetate of lead dissolved in water, filter, and weigh the precipitate, which is sulphate of lead· every 76 grains of this sulphate of lead require 95 or more (safely, 90) grains of lead acetate to insure sufficient decomposition. Calling grains pounds, the operation may then be conducted on a large scale. The excess of lead acetate in the acetate of iron mordant may be ascertained by diluting a little of the clear liquor with water, and adding a few drops of sulphuric acid; if it becomes cloudy, there is an excess of lead acetate which may prove injurious to colours, but this is easily obviated by adding ferric sulphate until the clear liquor is no longer affected by sulphuric acid. For the ordinary operations of the dyer it may not be necessary to decompose all the sesquisulphate of iron; but for printing, and particularly for full russets, the salt with which the goods are charged should be wholly ferric acetate, since if sulphate was contained some of it would disappear in washing the goods, whilst the basic acetate of iron cannot be removed by water.

The acetates of iron are employed in woollen dyeing to produce blue with potassium ferrocyanide (K_4FeCy_6), yellow prussiate; in cotton dyeing and printing, and in silk dyeing, they are used for blacks, russets, &c. Ferrous acetate is used with madder, for violet; or together with red liquor, for brown; it is also used for dyeing hats and furs black, and for blackening leather, wood, &c. Some dyers prefer the ferrous acetate, because, by the oxidation of the iron subsequent to dyeing, the colours are more resistant; but greater uniformity of the ground is insured by the use of ferric acetate.

An iron mordant containing a mixture of ferric and ferrous acetates is largely used; it is made by pouring pyroligneous acid on iron turnings in a series of vessels placed obliquely one above the other—as will be more particularly described under acetate of lead—suffering the acid to remain some length of time in contact with the metal, and repeating the operation until the acid is saturated with iron. This is the method now almost universally employed for the manufacture of these valuable mordants.

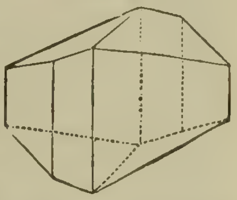
LEAD ACETATES.—These are the following:—

Neutral acetate or diacetate,	.$Pb(C_2H_3O_2)_2$.
Sesquibasic acetate, ...	$2(Pb\ C_2H_3O_2)_2), Pb(HO)_2$.
Dibasic acetate, ...	$2(Pb\ C_2H_3O_2)(HO)) + H_2O$.
Tribasic acetate, ...	$Pb(C_2H_3O_2), 2PbO, H_2O$.
Sexbasic acetate, ...	$Pb(C_2H_3O_2)(HO), 2PbO$.

Neutral Acetate, Diacetate, Sugar of Lead, Salt of Saturn; Sucre de Saturne, French; *Bleizucker*, German; $Pb(C_2H_3O_2)_2$.—As may be seen, lead unites with acetic acid in various proportions; the most important of these combinations is the normal salt, known in commerce as sugar of lead. It is used to a great extent in the calico-printing business, and likewise in dyeing, for the preparation of other compounds employed in those trades, and occasionally as a medicinal agent, and in pharmaceutical preparations.

It may be prepared by digesting litharge, monoxide of lead (PbO), in dilute acetic acid, or by exposing thin sheets of lead in a chamber to the joint action of air and the vapour of acetic acid. The lead becomes corroded, and a mixture of carbonate and acetate of lead is formed on the surface of the sheets. When this coating becomes thick enough it is scraped off, and dissolved in a slight excess of acetic acid. On evaporating this solution until it attains the density of 2·2, the lead acetate crystallizes, if the hot solution be set aside to cool rapidly, in clusters of fine needles; but if the evaporation be conducted slowly, the crystals are truncated and flattened quadrangular and hexahedral prisms (Fig. 35), derived from a right rhombic prism. The crystals are permanent in the air, but are apt to effloresce and become anhydrous if the temperature ranges between 70° and 100° Fahr. (21° and 38° C.). Anhydrous acetate of lead is soluble in boiling absolute alcohol, and is deposited again in hexagonal plates on the slow cooling of the spirituous solution. Acetate of lead has a sweet astringent taste, is soluble in less than $3\frac{1}{2}$ times its weight of boiling water, and in nearly the same quantity of cold water. PAYEN states that 100 parts of water at 60° Fahr. dissolve 59 parts of the crystallized acetate of lead. Its solution reddens litmus. The crystallized salt is fusible in its water of crystallization at 167° Fahr. (75° C.); just below 212° Fahr. (100° C.) it loses its water and part of its acid, and becomes converted into a white laminated mass of sesquibasic acetate.

Fig. 35.



On raising the temperature higher the substance fuses, is completely decomposed, and evolves all the compounds usually obtained in the destructive distillation of the acetates of the heavy metals, leaving a residue of metallic lead, in a very minute state of division, with some charcoal. When this distillation is conducted in a glass tube closed at one end, and having the other drawn out for convenience of sealing at the end of the operation, the well known lead pyrophorus is made. The particles of metallic lead are so small that when thrown into the air oxygen molecules come into such intimate contact with them, that ignition is effected from the rapidity with which lead oxide is formed.

A slight decomposition occurs when the neutral salt is exposed to an atmosphere of carbonic acid—carbonate of lead being formed; the portion of acetic acid thus liberated protects the remainder from further change.

KRAFT prepares lead acetate by treating 100 parts of lead sulphate with 52 parts of calcium acetate or 84 parts of barium acetate. In the cold the reaction is complete in a very short time; when the mixture is heated the change is instantaneous.

Brown Acetate of Lead.—Distilled pyroligneous acid is saturated with litharge in a tub, and the muddy solution ladled out into a large tun to settle; the solid matter quickly subsides, and the clear solution is then transferred into either a cast or wrought iron pan, about 6 feet long by 4 feet broad. The solution is here brought to the boiling point and then allowed to settle; it is next transferred into a large hemispherical pan capable of holding 300 or 400 gallons, where it is evaporated down to about crystallizing strength. When the solution has become dense enough to crystallize, about three times its bulk of water is run in upon it whilst boiling, the solution being constantly stirred. By this treatment the impurities are disengaged, and may be skimmed off as fast as they rise to the surface; after they are removed the evaporation goes on as before. If the solution be still too much coloured, another dose of water must be given. A little practice soon enables the operator to know when the evaporation should be checked. The ordinary method used by the workman is to rinse the skimming ladle through the liquid, and holding it above the pan, observing how many drops fall from it before the solution takes a stringy appearance; if only ten or twelve fall, then it is sufficiently strong. The liquid is now ladled out into wrought-iron pans to crystallize; the pans are 5 feet long by 3 feet broad, and about 6 inches deep, the sides being bevelled or sloping outwards from the bottom. After the crystals have become sufficiently firm, the sugar of lead is taken out by inverting the pan on a cloth. The pots used in the above process are heated only at the bottom.

White Acetate of Lead.—This is prepared by dissolving litharge in acetic acid. The acetic acid is introduced into a vessel, the litharge added by degrees, and the menstruum kept in brisk commotion after each addition, until the solution only slightly reddens litmus paper; a quantity of water, equal to about one-half of the acid employed, is then run into the lead solution; heat is applied, and the mixture slowly evaporated for about twelve hours, or until it has acquired a density of about 1·500. During evaporation any impurities which rise to the surface are skimmed off, and when the solution has acquired its proper gravity it is drawn into the crystallizing pans. When the crystals have become sufficiently hard to allow of their being taken *en masse* from the crystallizers, they are drained and placed on wooden racks in the drying-house, and, when dry, cleaned and broken up into fragments for the market.

The mother liquor, which contains neutral and basic acetates of lead and other metallic salts, may either be treated with vinegar, evaporated, recrystallized, and the residue employed as washings in subsequent operations; or it may be decomposed by the carbonates of soda or lime, and used as carbonate of lead; or dissolved in acetic acid, and the supernatant acetate of soda or lime recovered.

The vessels used in this manufacture are, in most cases, of lead. In Wales the mixing pans are of lead, three-quarters of an inch thick, 7 feet long by 4½ feet wide, and 1 foot deep. These pans are set on iron plates over arches, and the fireplaces are outside the building, in order that the acetate may not be discoloured by the smoke, &c., from the coal. The crystallizing pans are of wood, lined with thin copper, and are about 4 feet long by 2 feet wide, and from 6 to 8 inches deep, sloping inwards at the edges. At Pitchcombe both the mixing and crystallizing vessels are of copper, having a strip of lead soldered down the sides and across the bottom of the vessel, with the idea of rendering the metal more electro-negative, so as to prevent the acetic acid from acting on it. Very great care is requisite in the drying of the sugar of lead; the temperature of the desiccating house should not exceed 90° Fahr. (32° C.). In Wales the heated air of a stove, placed outside the drying-house, is conveyed through pipes passing round the interior; at other places steam heat is the agent for this purpose, which is much to be preferred on account of its being more easily regulated.

That the manufacturer may the better judge of the success of his operations from the amount of the product obtained, the following will serve as a precedent:—112 lbs. of good Newcastle litharge should produce 187 lbs. of sugar of lead, when treated with 127 lbs. of acetic acid of spec. grav. 1·057, but not more than 180 lbs. are obtained in practice. In a factory in Wales a ton of Welsh litharge produces, with the acid obtained from one ton of acetate of lime, from 28 to 30 cwts. of sugar of lead, and in another manufactory, one ton of best Newcastle litharge, with the acid from 1½ ton of the acetate of lime, produces 33 cwts. of the lead salt.

The following process with metallic lead, recommended first by BERARD, is easily executed, and is said by RUNGE to yield a good product with great economy. Granulated lead, the tailings in the white lead manufacture, &c., are put in several vessels—say eight—one above the other, upon steps, so that the liquid may be run from one to the other. The upper one is filled with acetic acid, and after half an hour let off into the second, after another half hour into the third, and so on to the last or eighth vessel. The acid causes the lead to absorb oxygen so rapidly from the air as to become hot. When the acid runs off from the lowest, it is thrown on the uppermost vessel a second time, and carries off the acetate of lead formed: after passing through the whole series the solution is so strong that it may be evaporated at once to crystallize. There are two points of importance in this manufacture. Whatever method may be pursued, a strong acid should be employed, in order that less of it may be lost in concentrating the liquid, that time may be economized, and an acid reaction retained in the liquid, to prevent the formation of a basic salt.

It may not be amiss to call attention here to a process, patented many years ago, for preparing acetate of lead and other acetates, and for which fresh patents have recently been taken out. It consists in employing the acid in the state of vapour, to act upon the bases, instead of using it in the liquid form. A vessel is provided of adequate capacity for the quantity of acetate required, and constructed of such material as will not be readily destroyed by the acid. The top of this vessel is closed hermetically by a cover, fastened down by any convenient means, and in the lower part of the vessel is placed either a minutely-perforated false bottom, or a coiled tube of several convolutions, minutely perforated, to permit vapour to permeate freely. To prevent the loss of acid there is also placed, at different degrees of elevation, several perforated diaphragms, similar to the false bottom just mentioned, on each of which is spread a layer of litharge, after which the cover of the vessel is to be accurately closed. By means of an ordinary distillatory apparatus liquid acetic acid—strong or weak, pure or impure—is converted into vapour, which is then conducted by means of a pipe into the convoluted and perforated one before mentioned, or between the real bottom of the vessel and the perforated false bottom; hence the acetic acid, passing through the numerous perforations of the false bottom and diaphragms, diffuses itself throughout every part of the vessel, and forms the acetate of the particular metal used, which falls to the bottom of the vessel, in its descent meeting with the ascending streams of vapour, the acid of which renders it perfectly neutral. Meanwhile the more aqueous part of the vapour ascends, and in its passage through the successive layers of the base is deprived of its remaining acid, and at last as simple steam is allowed to escape through pipes at the top of the vessel. As this steam still maintains a boiling temperature, it is conducted through a worm and used to evaporate the acetate or mother liquor. Distillation of the acid is continued until the acetate in the vessel has acquired the proper degree of concentration for crystallization, which is easily ascertained by examining a small quantity drawn off by a tap at the bottom of the vessel, through which the whole contents are discharged when the operation is completed. As the process draws to its close the vapour issues from the vessel charged with a certain portion of acid; and that no loss may be sustained by its escape into the atmosphere, it is conducted into another vessel prepared like the first-mentioned, so that every particle of the acid issuing from the first vessel may be absorbed. The second vessel is then made the first, and the other recharged and made the second. As the temperature of the solution of the acetate can never exceed that of the vapour, the crystalline product is of fine quality.

Lead Sesquibasic Acetate, Triplumbic Tetracetate, $2(Pb(C_2H_3O_2)_2).Pb(HO)_2$.—This salt is obtained by heating the diacetate until it becomes a white porous mass; this is redissolved in water and set aside to crystallize. Sesquibasic acetate is soluble in both water and alcohol; its solutions are alkaline.

Lead Dibasic Acetate, Plumbic Monoacetate, $2(Pb(C_2H_3O_2)(HO)) + H_2O$.—One equivalent of lead diacetate is boiled with one equivalent of lead oxide; on cooling the salt crystallizes—

$$Pb(C_2H_3O_2)_2 + PbO + H_2O = 2(Pb(C_2H_3O_2)(HO)).$$

Lead Tribasic Acetate, Triplumbic Diacetate, $Pb(C_2H_3O_2)_2,2PbO,H_2O$.—Prepared by digesting at a moderate heat 7 parts of finely powdered litharge, 6 parts of lead acetate, and 30 parts of water: or into 100 volumes of boiling water is poured 100 volumes of aqueous diacetate solution, saturated at 86° Fahr. (30° C.), and afterwards a mixture of pure water at 140° Fahr. (60° C.), with 20 volumes of ammonia liquor free from carbonate. The vessel is then immediately closed, and in a short time abundance of tribasic acetate crystallizes out. This salt presents itself under the form of long needles. It is insoluble in alcohol, very soluble in water, its solution being alkaline. Tribasic acetate is the most stable of all the subacetates of lead. It takes a leading part in the manufacture of white lead by CLICHY'S process; it is, in point of fact, a solution of this salt which is decomposed by the carbonic acid and gives rise to the carbonate of lead, being itself at the same time converted into lead diacetate. In the Dutch process the formation of lead carbonate is, according to PELOUZE, also due to the formation of triplumbic diacetate on the surface of the sheets of lead, which is, in its turn, decomposed by the carbonic acid.

Lead Sexbasic Acetate, Triplumbic Monoacetate, $Pb(C_2H_3O_2)HO,2PbO$.—This body is prepared by digesting any of the preceding salts with lead oxide. It is a white powder slightly soluble in boiling water, from which it crystallizes out in silky needles, which consist of two equivalents of the salt combined with three equivalents of water.

Acetum Saturni consists principally of triplumbic monoacetate; it is prepared by boiling 9 parts of water with 3 parts of lead diacetate and 1 part of lead oxide. *Goulard water* or *lead vinegar* is an aqueous solution of this preparation: on account of its power of coagulating mucus, &c., it is much used for forming a skin over wounds and sores.

Solution of lead subacetates are used in chemistry for the precipitation of colouring matters, tannin, gums, &c. GUIGNET has observed that a solution of basic acetates of lead produces distinct precipitate in a liquor containing only one per cent. of a soluble nitrate.

All solutions of basic acetates of lead absorb carbonic acid with great avidity, and become turbid from the precipitation of lead carbonate; their reactions with litmus and turmeric are alkaline.

CALCIUM DIACETATE; *Acetate of Lime*.—This salt is formed in the manufacture of acetic acid when lime carbonate is dissolved in acetic acid liquors. The reaction is—

$$CaCO_3 + 2C_2H_4O_2 = Ca(C_2H_3O_2)_2 + H_2O + CO_2.$$

According to PELOUZE, carbonate of lime does not dissolve in the monohydrated acid. The pure salt crystallizes from alcoholic solutions in silky, acicular prisms, containing one equivalent of water ($Ca(C_2H_3O_2)_2 + H_2O$), they have a bitterish saline taste, and effloresce when heated to 212° Fahr. (100° C.); they are soluble in water and alcohol. The dry salt has the property of being phosphorescent in the dark, when triturated at 226° Fahr. (108° C.).

A curtailed account of the production of this compound was given when describing the preparation of pure acetic acid from pyroligneous acid, and likewise of the acetate of soda. A modification of the process, in order to produce a purer article for the market, will be now considered. The following is the mode of working in large factories:—The crude acid liquor from the distillation of wood, after separating the pyroxylic spirit, is either distilled or run off into other convenient vessels, according as the *grey* or *brown* acetate is to be the resultant product. In either case the subsequent procedure is the same: 500 or 1000 gallons of the liquid are run off into wooden or iron vessels, of suitable capacity, and powdered chalk or slacked lime added, till a slight excess remains undissolved, and the whole agitated briskly for some time, in order to insure complete combination. The mixture is then allowed to rest at a temperature of 150° Fahr. (65° C.), till the excess of lime and tarry compounds subsides, when the clear supernatant liquid is siphoned off into the evaporating pans. These are, in most factories, wooden vessels lined with lead, and heated by coils of iron pipes placed within them, through which steam passes; occasionally they are shallow, and made of sheet-iron, and placed together directly over the fire. The solution of the lime salt is kept simmering, and briskly agitated during the evaporation, and the scum of tarry impurities that agglomerates at the surface constantly skimmed off. As soon as the acetate of lime begins to form it is separated from the liquor by the skimmers, and thrown into wicker baskets suspended over the pans, so that the solution draining from the salt may not cool.

The subjoined results were obtained by the use of three sheet-iron pans of about 18 inches in depth, each capable of containing 450 gallons of the solution:—

	Number of gallons of liquor evaporated.	Producing of dry acetate of lime,
In the first six days, of twenty-four hours each,	7,020	78 cwt.
In the second six days, of twenty-four hours each,	8,060	92 "
In the third week of six days, of twenty-four hours each,	7,000	78 "

Two of the pans contained *brown* acetate of lime liquor.

The yield of acetate here mentioned is of course dependent upon the variety of wood submitted to distillation, as also upon its state of dryness and the proper regulation of temperature. That part of the process which demands the greatest attention is the *drying*, as on its proper execution the success of the operation in a great measure depends. Many methods are in use for drying the lime salt, some of which are very unscientific. In some factories the salt is dried by spreading it in thick layers on the top of the brickwork surrounding the carbonizing retorts and steam-boilers; of course, in large works, where 10,000 to 15,000 gallons of liquor are evaporated weekly, the products cannot be dried in this way. When working on so large a scale it is customary to have a drying-house set apart for the purpose, and when the lime is burned on the premises the heat from the kilns is commonly used to dry the lime acetate, by conducting the products of combustion through flues in the floor of the drying-house. As a rule, there should be a drying-house attached to every factory, since the want of it may entail the loss of the whole of the acetic acid produced by the distillation of the wood.

The ordinary drying apparatus is a simple wind furnace, 7 or 8 feet long and 4½ feet broad, built of brick. At 6 inches above the ground is the ashpit, 8 inches broad and 12 inches high, which is covered with a grate of bricks. The fireplace is 20 inches high and 10 inches broad at the grate; over it is an arch of bricks, so that the fire cannot play on and heat very highly the iron drying-plate lying on the side of the hearth. The space below the drying-plate is separated from the hearth by a partition of bricks 3 or 4 inches high; 12 inches above the outlet of the hearth is a layer of iron bars 1½ to 2 inches from each other, and upon these is deposited the drying-plate. This consists of cast iron a quarter of an inch thick, and is formed according to the size of the furnace. Round the plate the furnace is built up to the height of 10 inches on the side of the front wall, leaving room for doors, which may be calculated at 2½ feet. These doors are two, one above the other, through which the whole interior of the furnace can be inspected. They are formed of plate iron, and have in their middle a sliding door to admit of the exit of the vapour of the acetate of lime and of some ventilation. A wall built at the end of the plate, or a clay partition, separates the whole of the drying-plate from the chimney. In the walls of the furnace iron bars are fixed, and upon these a second drying-plate covers the drying space. This plate, as it does not come in contact with the fire, may consist of good iron or of clay. Above this drying space another is formed by means of the chimney. The hot air passes both under and above the drying space, and thence into the chimney, which is situated at the side of the furnace, and can be shut by a valve. The prevailing temperature in the drying room is 167° to 235° Fahr. (75° to 112° C.).

When the whole of the furnace is heated to the proper temperature the fire is slackened. If wood be employed for fuel the sliding door should be opened at the commencement, in order to allow the moisture to escape. The salt is transferred from the baskets over the evaporating pans to the drying-plate, and spread out to the depth of 2 inches; and after the first portion has become somewhat dry the depth is increased to 4 or 5 inches; the heat, as already mentioned, is kept up for twenty-four hours, during which the salt is repeatedly turned. Subsequently, when the mass appears to be becoming dry, the temperature is raised to 257° Fahr. (125° C.), in order to expel every trace of water; care, however, must be taken that the heat is gradually applied, and that no vapours arise from the acetate of lime, for decomposition of the salt would then be taking place; neither should any spark of fire be suffered to come in contact with the dried salt, since it possesses the characteristic property of igniting and burning like sugar of lead. During the drying process the tarry and oleaginous matters with which the acetate is impregnated are decomposed, and a black charcoal remains, which appears in streaks through the dry mass. On dissolving the desiccated acetate of lime in 3 parts of hot water, and filtering through coarse animal charcoal or gravel, the charcoal and decomposed carbonaceous matters of the salt are separated; and the solution, upon evaporation to dryness, yields a very pure and nearly colourless product: 140 lbs. of this salt is the average produce of 1 ton of wood.

Manganese Acetate, $Mn(C_2H_3O_2)_2$.—This compound is prepared by dissolving pure manganese carbonate ($MnCO_3$) in acetic acid, evaporating the solution, and crystallizing. The crystals are of the rhombic prism, and occasionally in plates of an amethystine colour; they are permanent in air, soluble in alcohol and in about three and a half times their weight of cold water.

On the large scale this salt is manufactured by precipitating a solution of the manganous sulphate by one of lime acetate, and agitating the liquor to decompose the whole of the manganese salt.

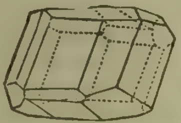
$$MnSO_4 + Ca(C_2H_3O_2)_2 = Mn(C_2H_3O_2)_2 + CaSO_4.$$

It sometimes happens that a portion of the manganese salt is not acted upon by the acetate of lime; in this case a concentrated solution of acetate of lead is employed towards the end of the process to effect the complete decomposition. The mixed precipitate of sulphate of lime and lead is filtered off, and the filtrate evaporated and crystallized, or, if deemed necessary, used directly. The best acetate of manganese is made by adding to 4 parts of manganous sulphate, dissolved in 3 parts of water, 7 parts of crystallized acetate of lead dissolved in 3 parts of water, agitating the solution, and drawing off the clear liquor for use.

Acetate of manganese is used in dyeing and calico printing, to give a brown colour to fabrics. Its principle of action depends upon the further oxidation of the manganese. The cloth is well steeped in a concentrated solution of the acetate of manganese, and printed; it is then passed through a bath containing bleaching powder, which oxidizes the manganese, producing a brown colour on that which, previous to its immersion in the bleaching or chloride of lime solution, was colourless.

Sodium Acetate, *Acetate of Soda; terre foliée minérale*, French; $NaC_2H_3O_2$.—This salt is formed by dissolving carbonate of soda in acetic acid, evaporating the solution, and setting the liquor aside to crystallize. The crystals are oblique rhombic prisms (Fig. 36) soluble in 3 parts of cold, in a less quantity of boiling water, and in 5 of alcohol. Their composition is $NaC_2H_3O_2 + 3H_2O$.

Fig. 36.



This salt possesses a pungent but not disagreeable taste. It is soluble in 3·9 parts of water at 44° Fahr. (6° C.), in 2·4 at 99° Fahr. (37° C.), and in 1·7 at 117° Fahr. (48° C.). According to Gerardin, 100 parts of alcohol at 0·9904 dissolved 38 parts of the crystallized salt at 65° Fahr. (18° C.). The solubility diminishes if the alcohol is more concentrated; alcohol 0·832 dissolves only 2·1 parts. When this salt is exposed to dry air it loses its three equivalents of water, but regains them in a moist atmosphere. After being melted this salt is deliquescent, and takes up 7 equivalents of water; it then becomes a liquid supersaturated solution, which crystallizes with evolution of heat immediately a fragment of dry or crystallized or sodium acetate is thrown into it.

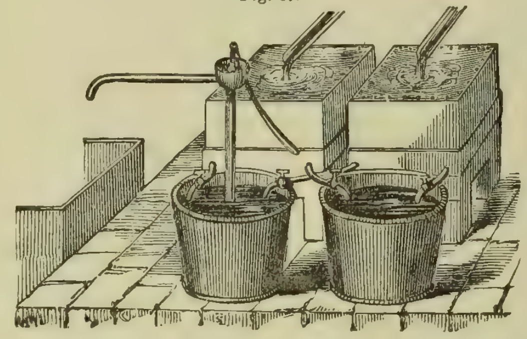
On the large scale the manufacture may be carried out in the following way:—A filtered solution of the common acetate of lime is precipitated by one of sulphate of soda at 98° or 100° Fahr. (36° to 38° C.), till the whole of the lime is thrown down as sulphate. (This process is not economical, on account of the formation of the double sulphate of calcium and sodium, $CaNa_2(SO_4)_4$.) The strength of the solution of the lime-salt is 1·116, and of the soda solution 1·250; or the sulphate of soda may be added in powder, and the whole well agitated until no further precipitation of sulphate of lime takes place, using the precaution, however, of adding the sulphate of soda sparingly, so as to prevent its excess. The mixture, after thorough agitation, is drawn off into a deep vessel and allowed to repose; and when the precipitated sulphate of lime has completely settled, the clear liquor is siphoned off and conducted to the evaporating pans for crystallization, the remaining lime-salt being washed with successive portions of water, till the whole of the acetate of soda is separated. The first washings may be added to the strong solutions in the evaporating pans, and the others retained for dissolving fresh portions of acetate of lime for subsequent decomposition. The process now most generally adopted is to distil the acetate of lime (after purification) with sulphuric acid, and saturating the acetic acid evolved with sodium carbonate.

Occasionally the solution of rough acetate of soda is filtered, and the precipitate washed in the following manner:—One or two backs are provided, according to the size of the factory; these are placed over two cisterns, each cistern being connected with both the backs by pipes branching from the latter to both cisterns; by means of a stop-cock in those connecting pipes the communication in either back may be cut off at will when required, as seen in Fig. 37. The backs are either square or circular, having false bottoms, in which are filters of stout twilled flannel. The charge from the decomposing pan is run on to one of the backs and filtered, till the whole of the strong liquor has passed into one of the cisterns; the connection with this cistern is then cut off, and when the washing of the residue commences the pipe communicating with the other cistern is opened, and conducts the washings into it. A fresh charge may then be introduced into the second back, and the pipe reaching to the cistern holding the strong liquor opened. Thus the strong liquor is always obtained by itself ready for evaporation. Another advantage is, that while the residue in one back is in the course of being washed, the other may be filtering off strong liquor. The washing is continued till the percolations are nearly tasteless; the residuum is dug out of the filters with wooden spades; iron spades cannot be used, as they are apt to cut the filters. The acetate of soda liquor is then pumped from the cisterns into the evaporating pans, which should be so constructed as to offer as much heated surface as possible, so that one man can keep their contents in brisk agitation. As the evaporation draws to a termination, much care and skill are required to keep the liquefied salt well stirred, so that every part may be equally under the influence of the heat, and decomposition of the whole mass prevented. The temperature should never rise higher than 500° Fahr. (260° C.), and in drying the acetate of soda 450° to 470° Fahr. (237° to 243° C.) is the temperature that should be applied. White fumes passing off from the fused mass are indicative of the decomposition of the salt; and if the fire be not checked immediately nothing will be left but carbonate of soda and charcoal.

If purified acetate of lime or pyroligneous acid be employed, the acetate of soda obtained by dissolving the above product in water, evaporating and crystallizing, will be quite pure.

Crystallization is conducted by dissolving the fused salt in twice its weight of water, and filtering the solution through filter-bags. The liquor is then evaporated till it acquires a spec. grav. of 1·50, when it is drawn off to the crystallizing pans. These may be made of boards lined with four-pound lead, 4 feet long, 2 feet wide, and 9 inches deep. The concentrated solution of the salt is left in the pans for two, three, or four days, according to the temperature of the room, till a crop of crystals are produced; the crystals are separated and deposited in baskets, where they are allowed to drain; the mother liquor is either returned to the evaporating pan, or is employed to dissolve fresh quantities of the crude salt. The crystals are washed with cold water, to separate any adhering mother liquor, and placed on shelves to dry, after which they are ready to be packed. The washings may be added to the mother liquor, and used as above.

Fig. 37.



The purification of this salt may also be effected in the following way:—The acetate of soda is dissolved in a large cylindrical lead vessel, heated by shooting steam into it. When the solution is completed it is run through a flannel filter into the top of a course of steamers, each furnished with a coil of three-quarter inch lead pipe. These vessels are made of four-pound sheet lead, cased in boards; the best size is about 24 feet long, 4 feet wide, and 9 inches deep. The pipe should be coiled from one end of the pan to the other, and should go up and down two or three times. Too much pipe cannot be used, as the rapidity of the evaporation depends upon the quantity employed. As the evaporation proceeds the liquor ought to be siphoned from the top to the second, and afterwards to the third steamer, and thus room made for more of the bulky weak liquor from the dissolving vessel. When a pellicle appears on the surface of the acetate solution it should be siphoned off into the crystallizers, and allowed to rest for two or three days, when beautiful crystals in oblique rhombic prisms will make their appearance. If large crystals are required the coolers are immersed in sawdust, or some other non-conducting material, and a longer time is allowed for them to form. In general cases the amount of acetate of soda obtained from 1 ton of the lime-salt ranges from 20 to 22 cwts. The impurities present in acetate of soda are sulphate of soda and acetate of lime; the presence of the latter is caused by the imperfect decomposition of the acetate of lime by sulphate of soda, and of the former by a too abundant use of that salt in decomposing the acetate of lime. The sulphate of soda is separated by skimming off the crystals of this salt, which form before those of the acetate of soda; but the acetate of lime cannot afterwards be got rid of, and is injurious in *running the crystals*, as the workmen term it; that is to say, it prevents crystallization. In some factories, instead of evaporating the acetate of soda to dryness, and subsequently roasting the dry mass, the purification is effected by repeated crystallizations and filtrations of the solution through animal charcoal, which has been previously washed with hydrochloric acid.

Sodium acetate has recently been used by Sacc with great success for the preservation of animal and vegetable substances. His method consists in the use of powdered acetate of sodium instead of common salt. To keep meat fresh, it is placed in a cask with layers of acetate of sodium interposed between the layers of meat in the proportion of one-fourth of the weight of the meat. In summer the action of the salt is immediate; in winter it is necessary to place the casks or barrels in a room heated to 58° Fahr. (44°·5 C.). As the salt abstracts the water from the meat, the cask is turned about. The operation is complete in about forty-eight hours, and the meat may then be packed with its pickle, or it may be dried in the air. If the casks are not full they may be filled up with a fresh pickle made by dissolving 1 part of acetate of soda in 3 parts of water. When the pickle is drawn off from the meat half the salt is deposited in crystals, and may be used again.

Meat which has been thus treated is prepared for cooking by steeping for at least twelve, and not more than twenty-four hours, according to the size of the piece, in tepid water, to which a small quantity of sal ammoniac has previously been added. This salt decomposes the acetate of sodium which remains in the meat, forming sodium chloride, or common salt, and ammonium acetate. The meat swells and resumes the colour and reactions of fresh meat. Animals, particularly fish and poultry, may be preserved entire for market purposes in a pickle of acetate of soda; the only precaution necessary being the removal of the intestines. Under the influence of the pickle the meat loses about one-fourth of its weight, and another quarter disappears when it is dried. The process is also said to be very well adapted to the preservation of vegetables. These generally lose thereby five-sixths of their weight. When needed for use, it is only necessary to soak them for twelve hours in water, and then cook them as if entirely fresh. It is necessary to scald vegetables until they lose their stiffness before applying the acetate of soda. After being twenty-four hours in the pickle at the temperature of about 86° Fahr. (30° C.), they are drained or pressed, and are then dried in the air. Potatoes must first be steamed, as they are not readily penetrated by the acetate of soda liquor. All articles of food prepared by this process should be kept in a dry place, as they would otherwise absorb moisture very quickly.

POTASSIUM ACETATES.—These are two in number—namely, the neutral acetate or monoacetate, and the acid acetate or diacetate of potassium.

Potassium Neutral Acetate, *Monoacetate of Potassium; Terra Foliata Tartari*, *Arcanum Tartari*, *Tartarus Regeneratus*, Alchemists; *blättererde*, *geblätterte weinsteinerde*, German; $KC_2H_3O_2$. — Acetic acid is present in the sap of very many plants, and is generally combined with potassium, forming neutral potassium acetate. When wood is calcined the potassium acetate is decomposed, the acetic acid being replaced by carbonic acid. It is by this interchange that the carbonate of potassium found in wood ashes is formed.

This salt may be prepared by any of the processes used to make sodium acetate. If prepared by dissolving carbonate of potassium in brown vinegar, FREMY advises that the carbonate be added in small portions at a time, and that care be taken to keep the liquor acid, by which means the formation of colouring matters by the action of the alkaline carbonate will be avoided.

Potassium monoacetate is generally deposited as a white foliated crystalline mass. The solution is evaporated to dryness, and cautiously fused, when the potassium monoacetate forms a white foliated crystalline mass. It is very soluble in water, and very deliquescent. According to OSANN:—

	Fahr.	C.
1 part of potassium acetate dissolves in 0·531 parts of water at	36°	2°
1 part of potassium acetate dissolves in 0·437 parts of water at	57°	13°9
1 part of potassium acetate dissolves in 0·321 parts of water at	83°	28°5
1 part of potassium acetate dissolves in 0·203 parts of water at	144°	62°

BERZELIUS states that 0·125 parts of boiling water dissolves 1 part of salt.

Acetate of potassium is less soluble in alcohol than it is in water. From a concentrated boiling alcoholic solution it crystallizes out on cooling. It is precipitated from alcoholic solution in the cold by ether. Carbonic acid passed into the alcoholic solution decomposes the salt, forming carbonate of potassium and acetate of ethyl (acetic ether). When dissolved in acetic acid, it forms the acid salt, potassium diacetate.

Potassium acetate melts at 556° Fahr. (292° C.); at a red heat it is decomposed into acetone, hydrocarbons, empyreumatic products, and a residue of carbon and potassium carbonate.

Acetate of potassium, when heated with potassium hydrate in excess, becomes converted into carbonate of potassium and marsh gas:—

$$\overset{\text{Potassium acetate.}}{KC_2H_3O_2} + \overset{\text{Potassium hydrate.}}{KHO} = \overset{\text{Potassium carbonate.}}{KCO_3} + \overset{\text{Marsh gas.}}{CH_4}.$$

When heated with arsenious acid cacodyl is produced. This reaction is so decided, and the alliaceous odour evolved is so strongly marked, that it forms one of the best tests for small quantities of acetic acid.

KOLBE first obtained free methyl by the decomposition of acetate of potassium by electrolysis.

Potassium acetate is employed in medicine as a diuretic.

Chlorine gas dissolves in an aqueous solution of acetate of potassium, forming a powerful though unstable bleaching liquor; carbonic acid is evolved during the reaction.

Potassium Acid Acetate, *Potassium Diacetate*, $KC_2H_3O_2,C_2H_4O_2$.—This salt was first formed by THOMSON, by evaporating an equivalent solution of potassium acetate in acetic acid in vacuo. Subsequently it was found by MELSIUS to be readily formed by dissolving acetate of potassium in an excess of acetic acid, and evaporating to dryness; the salt crystallizes in fine needles or oblate rhombic prisms, as the evaporation is rapid or the reverse.

STANNOUS ACETATE, *Acetate of the Protoxide of Tin*, $Sn(C_2H_3O_2)_2$.—This salt is employed in calico-printing, to give light spirit colours to cloth. The process of manufacture is nearly the same as that for making sodium acetate. The proportions taken are, 103 parts of crystallized tin dichloride (stannous chloride, $SnCl_2$), dissolved in water, and 190 parts of crystallized lead acetate. It may likewise be prepared by dissolving tin oxide, or metallic tin, in acetic acid. In technical operations, the first method is usually followed. On evaporating the filtered solution to a syrupy consistence, and adding alcohol, the salt crystallizes in colourless transparent needles, which have a great tendency to oxidize, if at all exposed to the air.

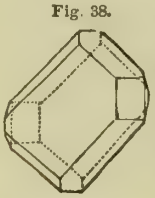
Another recipe is to dissolve 30 lbs. of acetate of lead in 40 gallons of boiling water, and add 18¾ lbs. of crystals of chloride of tin; the mixture is then well stirred, allowed to settle, and the liquor filtered or siphoned off for use into casks or vessels, protected as much as possible from contact with the air. Some makers prefer to prepare the salt when immediately wanted for use.

Hydrated stannic oxide (stannic acid, H_2SnO_3) also dissolves in acetic acid. On evaporation it yields a gummy uncrystallizable mass.

Zinc Acetate, $Zn(C_2H_3O_2)_2$.—This salt may be prepared by dissolving metallic zinc, zinc oxide, or zinc carbonate, in acetic acid, or by the decomposition of zinc sulphate by acetates of lime or lead, similar to the acetate of manganese; the decompositions in these instances being represented in the annexed equations:—

$$Zn + 2C_2H_4O_2 = Zn(C_2H_3O_2)_2 + 2H.$$
$$ZnO + 2C_2H_4O_2 = Zn(C_2H_3O_2)_2 + H_2O.$$
$$ZnCO_3 + 2C_2H_4O_2 = Zn(C_2H_3O_2)_2 + H_2O + CO_2.$$
$$ZnSO_4 + Pb(C_2H_3O_2)_2 = Zn(C_2H_3O_2)_2 + PbSO_4.$$

Fig. 38.



The acetate is obtained in the first three instances simply by evaporation, and in the latter, after agitating the mixture, filtering and evaporating the filtrate, the salt crystallizes in flexible, opalescent, six-sided tables, Fig. 38, which effloresce slightly in the air. According to Schindler, the crystals contain 3 equivalents of water when deposited from cold solutions, but only 1 equivalent when they are formed from concentrated hot ones.

Technically, the best recipe is to dissolve 4 parts of the sulphate of zinc, and 7½ parts of acetate of lead, each in 3 parts of hot water, mixing the solutions, agitating, and after the sulphate of lead has deposited, drawing the clear liquid off to crystallize.

Metallic Acetates.—The acetates are characterized by the pungent odour of acetic acid which they emit when heated with sulphuric acid. When heated with lime they furnish acetone, which has a peculiar and unmistakable odour. When distilled with caustic potash they yield marsh gas (upon this reaction the best method of obtaining this gas is founded). Heated with arsenious oxide (As_2O_3), metallic acetates give rise to cacodyl (arsen-di-methyl, $As_2(CH_3)_6$, By this reaction extremely minute quantities of acetic acid can be detected.

Pyroxylic Spirit or Wood Naphtha.—*Hydrate of Methyl, methylic alcohol, wood spirit; ésprit de bois*, French; *holzgeist, holzessiggeist*, German. Formula—

$$CH_4O = CH_3\,(OH) \text{ or } \left.\begin{matrix}CH_3\\H\end{matrix}\right\}O.$$

This substance was first observed by Taylor in 1812, in the watery liquid obtained by the destructive distillation of wood, and its properties were subsequently more fully investigated by Dumas and Peligot in 1835. Crude pyroligneous acid (wood vinegar) commonly contains about 1 per cent. of this alcohol, which is separated from the rest of the liquor by collecting apart the first portions which distil over. The acid solution thus obtained is neutralized with lime, and the clear liquor, when separated from the oil which floats on the top and the sediment which precipitates, is again distilled. The volatile liquid thus obtained is strengthened by rectification.

Pyroxylic spirit is a limpid, inflammable, colourless liquid, of a penetrating spirituous odour and a disagreeable burning taste. Its specific gravity is 0·8142 at 32° Fahr. (0° C.), 0·798 at 68° Fahr. (20° C.). Its boiling point varies according to the nature of the vessel, but may be taken as about 150° Fahr. (65°·5 C.). Wood spirit mixes with alcohol, ether, and water, and essential oils in all proportions; it dissolves most of the resins and gums, and is thus of considerable value in the arts, being used as a solvent in place of ordinary alcohol. It was formerly much used as a substitute for spirits of wine in spirit lamps. It burns with a very pale flame, producing in its combustion carbonic anhydride (CO_2) and water.

A solution of shellac and other resins in pyroxylic spirit is extensively used for stiffening the basis of silk hats. Furniture polishes are also made with it. The hydrates of the alkalies dissolve in wood spirit, but at the same time colour it brown. Ure proposed this reaction as a means of detecting small quantities of wood spirit when mixed with alcohol, since the latter is unaffected by alkalies until the lapse of a considerable time; whereas when alcohol contains even as little as 2 per cent. of wood spirit the addition of powdered caustic potash causes it to acquire a yellow tint in ten minutes, and to become completely brown in half an hour.

This alcohol has never been produced by fermentation. Berthelot has obtained it artificially by acting on marsh gas with chlorine, and afterwards decomposing the chloride thus formed with aqueous potash. As marsh gas can be produced synthetically, it follows that the synthesis of wood spirit is also practicable.

Methylic alcohol is decomposed by passing through a red hot tube into acetylene and other substances. By exposure to the air, in contact with spongy platinum or platinum black, it is oxidized to formic acid thus:—

$$\overset{\text{Methylic Alcohol.}}{CH_4O} + O_2 = \overset{\text{Water.}}{H_2O} + \overset{\text{Formic Acid.}}{CH_2O_2}.$$

Bleaching powder (hypochlorite of calcium) converts wood spirit into chloroform ($CHCl_3$).

$$CH_4O + 4Cl = CHCl_3 + H_2O + HCl.$$

Potassium and sodium dissolves in it with evolution of hydrogen, forming potassium and sodium methylates (CH_3KO and CH_3NaO). Chlorine gas decomposes wood spirit with flame and detonation, forming chlorinated compounds together with hydrochloric acid. Concentrated sulphuric acid produces methyl sulphuric acid (CH_3HSO_4). This liquid, when heated together with wood spirit, yields dimethylic sulphate, $(CH_3)_2SO_4$.

In order to prepare commercial wood spirit, the distillates from the wood are received in a tank or other suitable vessel, and the whole allowed to rest for some time. The greater part of the tarry and other resinous and oily matters soon precipitates, the spirit and acid liquor forming a supernatant layer, which is drawn off into another tank by means of an overflow pipe or siphon. The liquids are sometimes made to percolate a filter of coarse gravel in their passage from the first tank, by which expedient a large quantity of the matters held in suspension by the acid liquor is separated.

The purification of the spirituous and acid products is effected in two ways—In the first the spirit is distilled directly from the crude liquor; in the second the acid is neutralized with milk of lime before being submitted to distillation to obtain the spirit.

In the first instance the liquor is pumped into copper stills of about 500 gallons. Heat is sometimes applied by means of coils of copper pipe placed in the interior of the stills, through which steam from an adjacent steam-boiler is forced; in other cases the heat is applied externally, either by steam-pipes coiling round the still, or by the direct application of fire. The distillation is continued till nearly all the spirit has passed over, which is known by throwing a portion of the distillate on a bright fire; if much spirit still remains the liquor inflames, giving a whitish light.

In most instances the whole of the naphtha is expelled when about 100 gallons are condensed in the receiver. When no more vapours are eliminated the receiver is changed, and the distillation of the acid liquor proceeded with till nearly all the liquid has passed over; the remaining tarry and oleaginous products are then run off into a tank through a stopcock in the bottom of the still. Should the acid be not immediately wanted, the remaining 400 gallons, after the expulsion of the spirit, are drawn off into the tank and allowed to rest, so as to deposit the excess of impurities, and afterwards pumped up to other vessels as required.

In the second method instanced the acid liquor is first neutralized by means of hydrate of lime, and the spirituous and crude acetate of lime liquors afterwards distilled in sheet-iron stills or boilers to obtain the naphtha. Fire is applied directly to the under part of the boiler. The remaining acetate of lime liquor is drawn off, and allowed to remain in tanks or reservoirs till required for use. The deposit of tarry matters which accumulates in the first receiver of the condensing apparatus, attached to the wood carbonizer, is also subjected to distillation, and the crude spirit therefrom added to the former portions.

The further purification of the crude spirit obtained in the preceding distillation, is effected by repeated rectifications, over at first caustic lime, and then over a mixture of lime and caustic potassa; and in order to detach the small quantity of ammonia that is formed, the final distillation of the product is carried on with a little sulphuric acid. In some factories the distillates are rectified over chalk, and in some others over chalk and bicarbonate of soda. Copper stills are invariably used, and the heat applied either by steam pipes coiled in the interior of the still, or the lower half of the retort is encased in an iron jacket, to which the fire is directly applied.

The spirit thus obtained is colourless, and varies in specific gravity from ·870 to ·832.

A few years ago WILDSMITH obtained a patent for the purification of spirituous and acid products of the distillation of wood. The principle of his invention is the application of an oxidizing agent, together with the influence of light, by which treatment he proposes to oxidize the hydrocarbons, which are unessential to the spirit and acid, but whose presence communicates a disagreeable odour to the products. Bichromate and permanganate of potassa are the salts he prefers, and which he employs in the following manner:—"The liquors are placed in a tank secluded from the air or the accidental admixture with dirt or other impurities, by means of a glass or glazed cover, so as to admit the light, which is necessary for the success of this process. Four ounces, avoirdupois, of the forementioned compounds, in fine powder, are used to every imperial gallon of the liquid; this may be thrown into the tank with the liquid, or the salt may be dropped into the solution gradually, and the whole well agitated. The time required to effect the purification of the spirit depends upon the quantity of tarry matters present; but in ordinary cases from fourteen to twenty-one days will suffice. Sunny weather favours the purification of the spirit and acid from the foreign compounds, as it brings about the combination of the oxygen of the oxidizing agent with the carbonaceous impurities in a very considerable measure. Other compounds, such as oxide of manganese, or a properly regulated stream of chlorine gas passed through the solution, might answer the purpose equally well, but the permanganate and bichromate of potassa or soda offer the greatest facilities in their use; besides, they are, by effecting the intended purpose, converted into bodies which exert no diminishing action upon the substances sought, and which may be easily separated from the spirituous and acid liquor by distillation. When the purifying reagents have been added, the fluid should be agitated once or twice daily, in order to bring the solution of the salts into immediate contact with the impure liquor; during the intervals the cover should be kept on. Frames of glass or mica in the cover are made to slide backwards and forwards, in order to allow the liquid to be examined, and learn how far the purification has advanced. If it be desired to hasten the reaction, sulphuric or hydrochloric acid is added, in the proportion of 1 lb. of acid to 50 gallons of spirit. The object of these additions is to liberate the acid more freely from its combination with the potassa, and thus bring the whole of the oxygen within reach of the hydrocarbons and the other analogous impurities. When the oxidation of the impurities is completed, the liquor is distilled in the usual way, and a clear colourless product, without smell, and capable of being burned in lamps or used for any other required purpose, is obtained."

The general yield of pyroxylic spirit is from $1\frac{1}{4}$ gallon to $2\frac{1}{2}$ gallons, and occasionally as much as 3 gallons, from each ton of wood. This variation in quantity is often due to the kind of wood carbonized, but more frequently to negligence in regulating the proper degree of heat.

The subjoined tabular view of the percentage amounts of spirit in naphthas of different specific gravities was drawn up by Dr. Ure. The spirit operated upon in these experiments was purified by distillation over quicklime, at the heat of a water-bath, the temperature being so regulated that the liquid had a density of ·8136 at 60° Fahr. (15° C.).

Sp. gr.	Real Spirit, per cent.	Over Excise proof.	Sp. gr.	Real Spirit, per cent.	Over Excise proof.
·8136	100·00	..	·9032	68·50	13·10
8216	98·00	64·10	9060	67·56	11·40
8256	96·11	61·10	9070	66·66	9·30
8320	94·34	58·00	9116	65·00	7·10
8384	92·22	55·50	9154	63·30	4·20
8418	90·90	52·50	9184	61·73	2·10
8470	89·30	49·70			Underproof.
8514	87·72	47·40	9218	60·24	0·60
8564	86·20	46·60	9242	58·82	2·50
8596	84·75	42·20	9266	57·73	4·00
8642	83·33	39·90	9296	56·18	7·00
8674	82·00	37·10	9344	53·70	11·00
8712	80·64	35·00	9386	51·54	15·30
8742	79·36	32·70	9414	50·00	17·80
8784	78·13	30·00	9448	47·62	20·80
8820	77·00	27·90	9484	46·00	25·10
8842	75·76	26·00	9518	43·48	28·80
8876	74·63	24·30	9540	41·66	31·90
8918	73·53	22·20	9564	40·00	34·20
8930	72·46	20·60	9584	38·46	35·60
8950	71·43	18·30	9600	37·11	38·10
8984	70·42	16·16	9620	35·71	40·60
9008	69·44	15·30			

Deville has likewise completed a table, showing the quantity of real spirit in naphtha of different specific gravities at 50° Fahr. (10° C.), which differs somewhat from that of Ure. Deville considers that Ure's spirit contained some water.

Methylic Alcohol.	Specific gravity.
100 per cent.	0·8070
90 “	0·8371
80 “	0·8649
70 “	0·8873
60 “	0·9072
50 “	0·9232
40 “	0·9429
30 “	0·9576
20 “	0·9709
10 “	0·9751
5 “	0·9857

The same authority says, if the above results are brought to a temperature of 60° Fahr. it will be found there is an almost complete correspondence between alcohol and wood spirit, and that the latter, equally with the former, exhibits a maximum of contraction, which always occurs when one part of wood spirit is combined with three parts of water; that is, in a mixture containing 45·75 per cent. of water. The lowest specific gravity to which pyroxylic acid has been brought in this country is 0·812. Dumas, however, states that its density at the temperature of 68° (20° C.) is 0·798, and that of its vapour 1·120, and that its point of ebullition is 152° (66·5° C.) at a pressure of 30 inches. The true specific gravity appears to be 0·798, as found by Dumas and Mitscherlich; and from several experiments performed by Muspratt its boiling point ranges between 150° and 160° Fahr. (65°·5 and 71° C.).

Acetone, methyl acetate, dimethyl acetate, and the empyreumatic oils, being in variable proportion in wood naphtha, cause its density to alter considerably; its solvent power, as regards shell-lac, sandarac, and other resins, is likewise materially affected by the presence or absence of such bodies. Their existence is attributed to the various methods of preparing the spirit, and also to the want of proper care in managing the operations to which it is subjected. Pure pyroxylic spirit will not answer every purpose for which it is required in the arts. The purest, and that possessing the lowest specific gravity, is preferable for lamps as a source of heat; but for dissolving resins, and especially gum sandarac and mastic, painters and French polishers choose spirit holding some of the essential oils in solution. Wood spirit of a low specific gravity, and free from acetone, is procured by liming the raw liquor and distilling; whilst the best menstruum for resins is obtained by distilling off the refined portion of the crude liquor without saturating with the caustic earth. The spirit in the former case has an incipient gravity and is miscible with water, while in the latter it is weaker, and water renders it milky.

To procure pure pyroxylic acid, the crude commercial spirit is saturated with fused chloride of calcium, and heated on the water bath as long as volatilization continues. The chloride of calcium acts by combining with the methylic alcohol to form a solid crystalline compound, whilst the other substances present separate as an oily liquid, which is poured off; the last traces of acetone, methyl acetate, &c., are removed by heating the solid mass to 212° Fahr. (100° C.), at which temperature the calcium compound is not decomposed. On adding water, however, and distilling, the dry residue yields methyl alcohol, which is dried over quick lime and again distilled over a water bath. The alcohol thus obtained is not perfectly pure. To prepare the pure compound, methylic ether must first be produced. Purified wood spirit is mixed with its own weight of sulphuric acid and twice its weight of potassium binoxalate, and the whole distilled. As soon as crystals of methyl oxalate appear in the neck of the retort the receiver is changed, the distillation being continued as long as the ether comes over. The crystals are powdered and pressed between filter paper. On distilling this pure ether with water, methylic alcohol passes over and oxalic acid remains; thus:—

$$\underset{\text{Methyl Oxalate.}}{(CH_3)_2C_2O_4} + 2H_2O = \underset{\text{Methylic Alcohol.}}{2CH_4O} + \underset{\text{Oxalic Acid}}{C_2H_2O_4}.$$

The aqueous methylic alcohol is redistilled from a water bath, dried over quicklime, and then rectified.

Pure pyroxylic spirit is readily distinguished from acetone by adding to it a concentrated solution of chloride of calcium, which is miscible with the wood spirit, but not with the pyroacetic spirit, or acetone.

Methylated Spirit.—Common alcohol is used in so many manufactures as a solvent, that the duty on spirits was found to be a serious detriment to trade. The excise regulations, however, now permit the sale of a mixture of 10 parts of crude methylic alcohol (pyroxylic spirit) and 90 parts of absolute alcohol, duty free. This mixture, termed "methylated spirit," is suitable for all the ordinary purposes to which spirit of wine is applied in the manufactures, but cannot be used for making gin or other spirituous drinks, on account of its extremely offensive odour and taste. The methylic alcohol cannot be separated by distillation. Of late years methylated spirit has been used in nearly all the manufacturing processes in which pyroxylic spirit was formerly employed.

Acetic Ether.—*Acetate of Ethyl*, *Ethylic Acetate; essigäther*, *essignaptha*, *essigsaures æthyloxyd*, German; *ether acétique*, French; $C_2H_3O_2,C_2H_5$ or $C_4H_3O_2$.

This body is the most important of the numerous compounds termed generically acetic ethers.

It is formed by the substitution of the radicle of ethyl alcohol (spirits of wine, "alcohol" *par excellence*) for the basic hydrogen of acetic acid, thus:—

$$\begin{aligned}\text{Acetic acid} &= C_2H_3O_2 + H.\\ \text{Ethyl alcohol} &= C_2H_5 \quad + HO.\end{aligned}$$

$$\overset{\text{Acetic acid.}}{(C_2H_3O_2 + H)} + \overset{\text{Ethyl alcohol.}}{(C_2H_5 + OH)} = \overset{\text{Ethyl acetate.}}{C_2H_3O_2,C_2H_5)} + \overset{\text{Water.}}{H_2O.}$$

The radicle of any monatomic alcohol may in like manner replace the loosely attached hydrogen atom, and in this way are formed acetate of methyl ($C_2H_3O_2,CH_3$), acetate of butyl ($C_2H_3O_2,C_4H_9$), acetate of amyl ($C_2H_3O_2,C_5H_{11}$), and other acetates of monatomic alcohols. In like manner the radicle of benzyl alcohol, $C_7H_8O = C_7H_7(OH)$, forms benzyl acetate, $C_2H_3O_2,C_7H_7$:—

$$\overset{\text{Acetic acid.}}{(C_2H_3O_2,H)} + \overset{\text{Benzyl alcohol.}}{(C_7H_7,OH)} = \overset{\text{Benzyl acetate.}}{C_2H_3O_2,C_7H_7} + \overset{\text{Water.}}{H_2O.}$$

Ethyl acetate was discovered by Lauraguais in 1759. This chemist obtained it by heating alcohol with acetic acid. It is readily prepared by distilling to dryness 3 parts of potassium acetate with 2 parts of absolute alcohol; or 10 parts of sodium acetate, 6 parts of alcohol, and 15 parts of sulphuric acid; or 16 parts of dry sugar of lead, with 6 parts of sulphuric acid, spec. grav. 1·84, and 4½ parts of water. Heating must at first be conducted with great caution; as the distillation proceeds the temperature may be raised.

The fluid which passes over is first mixed with a weak solution of carbonate of soda, or some other alkali, till neutralized, and then the supernatant layer of aqueous acetic ether is drawn off and agitated repeatedly with dry potassium carbonate, until that salt is no longer moistened with it; the solution is then distilled to procure the pure ether. Chloride of calcium should not be used, since it is soluble in acetic ether, and gives rise to subsalts.

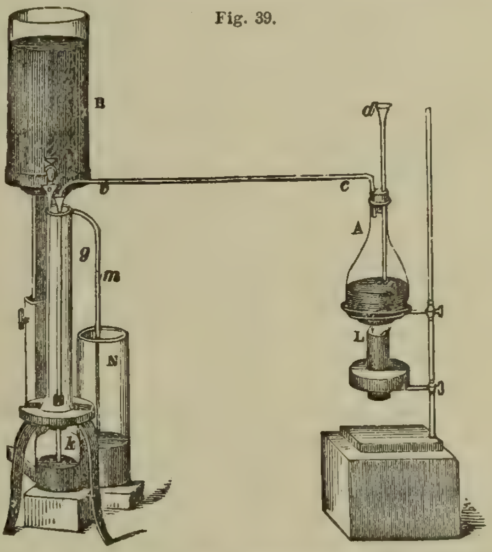
Acetic ether is a colourless mobile liquid, having an agreeable refreshing etherial odour and a pleasant taste; it burns with a yellowish flame, producing acid vapours. Its spec. grav. is 0·89 at 60° Fahr. (15° C.), 0·9146 at 32° Fahr. (0° C.).—Kopp. It boils at 165° Fahr. (74° C.), and is converted into vapour of spec. grav. 3·067.

Acetic ether is soluble in 11 to 12 parts of water, and in alcohol and ether in all proportions.

Fig. 39 is a convenient form of apparatus for making acetic ether. A is a large flask, furnished with an air-tight cork, perforated with two holes, through one of which a safety or funnel tube, *d*, passes, and the other receives the tube, *c c*, bent at right angles as seen in the figure, through which the vapours pass to the condenser. The condenser, *g*, is a wide cylinder, having an aperture at the bottom, through which the bent end of the tube passes into a flask, *k*, placed beneath the cylinder to receive the distilled products. A cistern, E, supplies the cylinder, *g*, by the stopcock, *j*, with cold water, which is conducted to the bottom by the funnel pipe, *o*, and the partly-heated water passes off by the overflow pipe, *m*, into the vessel, N. Heat is applied to the flask by means of the spirit lamp, L, or a Bunsen burner.

Acetic ether is unalterable in dry air; in a moist atmosphere it is after a time converted by absorption of water into acetic acid and alcohol. Heated with a caustic alkali, acetic ether splits up in like manner, an acetate and alcoholate being formed, thus:—

Fig. 39.



$$\overset{\text{Acetic ether.}}{2(C_2H_3O_2,C_2H_5)} + \overset{\text{Baryta.}}{2(BaO)} = \overset{\text{Barium acetate.}}{Ba(C_2H_3O_2)_2} + \overset{\text{Barium alcoholate.}}{BaO_2(C_2H_5)_2.}$$

Acetate of lead is the salt commonly employed when making acetic ether on a large scale; the proportions used being those given above. The sulphuric acid and alcohol are mixed in a vessel surrounded by ice, and the mixture, when cooled, is poured upon the finely-divided lead salt in the flask; the apparatus is adjusted, and a gentle heat applied at first, which is gradually increased towards the end of the distillation. The condenser is well cooled, and the receiver may be advantageously immersed in ice-cold water. The acetic ether obtained is rectified as before-mentioned.

When this ether is poured upon chloride of calcium, combination takes place, and a crystalline mass results, from which, by the addition of a small quantity of water acetic ether again separates. By digestion in a solution of potassa acetic ether suffers complete decomposition; acetic acid unites with the alkali, and ether passes off: the same effect is produced when the ether is distilled with lime. Heated with strong sulphuric acid, acetic ether is converted into oxide of ethyl (common "ether," $(C_2H_5)_2O = C_4H_{10}O$) and acetic acid. Hydrochloric acid converts it into chloride of ethyl (C_2H_5Cl) and acetic acid. Pure acetic ether does not react on blue litmus paper, nor should it be coloured by sulphuretted hydrogen. It dissolves resins, sulphur, phosphorus, &c., like ether.

This compound is a constituent of many wines; it is almost always present in wine vinegar, and is used as a constituent of several of the pharmaceutical preparations employed in medicine. From its power of dissolving resins and essential oils, it can be advantageously applied in the preparation of varnishes.

Acetate of Methyl, *Methylic Acetate*, *Pyroacetic Spirit; essigsaures holzæther*, German; *æther lignosus*—$C_2H_3O_2,CH_3$ or $C_3H_6O_2$. This liquid is one of the constituents of crude wood vinegar. It was first noticed by Dumas and Péligot in 1835. These chemists prepared it by distilling 2 parts of pyroxylic spirit with 1 part of glacial acetic acid and 1 part of sulphuric acid, and agitating the distillate with chloride of calcium. After allowing the mixture to settle the supernatant liquid is methylic acetate, contaminated with sulphurous acid and wood spirit. The former impurity is removed by agitation with quicklime, and the latter by leaving the methylic acetate in contact with chloride of calcium for twenty-four hours.

Weidmann and Schweizer, who first detected this compound in wood vinegar, prepare it by distilling a mixture of 2 parts pyroxylic spirit, 1 part of acetic acid, and 1 part of sulphuric acid; or 3 parts of wood spirit, 14½ parts of dry lead diacetate (sugar of lead), and 5 parts of sulphuric acid; or, and this is the mode they prefer, 1 part of potassium acetate and 2 parts of sulphuric acid. The distillation is arrested immediately sulphurous acid begins to be evolved, the excess of wood spirit is removed by chloride of calcium, and the liquid distilled from soda carbonate; further purification is effected as in the case of ethylic acetate (acetic ether *q. v.*).

Methylic acetate is a colourless liquid, having an odour much resembling that of acetic ether; its spec. grav. at 32° Fahr. (0° C.) is 0·9562, at 70° Fahr. (21° C.) 0·919.—Kopp. Vapour density, 2·563.—Dumas and Péligot.

Acetate of methyl is soluble in water, and mixes with alcohol, ether, and pyroxylic spirit in all proportions. Its aqueous solution is but slightly decomposed on boiling. Alkalies transform it into methylic alcohol and an acetate. Soda lime decomposes it with much violence into a sodium acetate and formiate, with evolution of hydrogen. Sulphuric acid splits it up into acetic acid and methyl sulphuric acid, much heat being given off during the reaction.

Acetone, *Pyroacetic Spirit*, *esprit pyroacétique*, of the French; *essiggeist*, *brenzessiggeist*, German—$C_3H_6O = C_2H_3O,CH_3$. The ketone of acetic acid. It is derived from acetic aldehyde by the substitution of the alcohol radicle CH_3, for the hydrogen in the group COH.—Gerhardt and Williamson.

$$\overset{\text{Acetic aldehyde.}}{CH_3,CO(H).} \qquad \overset{\text{Acetic ketone or acetone.}}{CH_3,CO(CH_3).}$$

This compound was first observed by Courtenvaux in 1754. The brothers Derosne subsequently investigated its properties, and named it pyroacetic ether. Chenevix, however, concluded from experiment that it was not an ether, and termed it pyroacetic spirit. Its composition was definitely ascertained by Dumas and Liebig.

Kane looked upon acetone as mesitylic alcohol, C_3H_5,HO (C_3H_5 being the radicle mesityl); but his views were proved to be erroneous.

This body occurs in the destructive distillation of all acetates. When required it is prepared by distilling barium or calcium acetate; acetone is given off, and the carbonate of the alkaline metal remains.

$$\overset{\text{Calcium diacetate.}}{Ca(C_2H_3O_2)_2} = \overset{\text{Acetone.}}{C_3H_6O} + \overset{\text{Calcium carbonate.}}{CaCO_3.}$$

When the alkaline acetate is pure the product is pure acetone. It can also be made by distilling in an iron retort a mixture of 2 parts of sugar of lead (lead diacetate) and 1 part of powdered quicklime. The product must in this case be saturated with potassium carbonate, rectified over chloride of calcium several times, and finally distilled by the heat of a water bath. The condenser must be kept carefully cooled, and only those products collected which pass over at 140° Fahr. (60° C.).

A large quantity of acetone is obtained as a bye product in the manufacture of aniline, when distilling the mixture of acetate of iron and aniline, produced by the action of iron and acetic acid upon nitrobenzene.

Acetone is likewise formed during the dry distillation, together with lime, of sugar, tartaric acid, gum arabic, and like substances; and also by the oxidation of citric acid, by heating it with permanganate of potassium or a mixture of binoxide of manganese and dilute sulphuric acid.—Pean de Saint Gilles.

$$\overset{\text{Citric acid.}}{C_6H_8O_7} + O = \overset{\text{Acetone.}}{C_3H_6O} + \overset{\text{Carbonic acid.}}{3CO_2} + \overset{\text{Water.}}{H_2O.}$$

When acetic acid is decomposed by being passed through a porcelain tube heated to redness, acetone is one of the products—

$$\overset{\text{Acetic acid.}}{2C_2H_4O_2} = \overset{\text{Acetone.}}{C_3H_6O} + \overset{\text{Carbonic acid.}}{CO_2} + \overset{\text{Water.}}{H_2O.}$$

Acetone is a colourless limpid liquid, having a very agreeable ethereal odour and a burning taste. Its specific gravity is at 65° Fahr. (18° C.) 0·7921, according to Liebig; at 32° Fahr. (0° C.) 0·814.—Kopp. Its vapour density is 2·0025.—Dumas. Its boiling point is 130° Fahr. (56° C.).—Dumas. It does not solidify at 5° Fahr. (— 15° C.). Acetone is very inflammable, and burns with a bright yellow flame. It is soluble in all proportions in ether, alcohol, and in water. It is a solvent for nearly all gums and resins, camphors and fats. Gun cotton dissolves in it with great facility.

Limpricht has formed definite compounds of acetone with the alkaline bisulphites. The solution of bisulphite should be very concentrated; the action then takes place somewhat rapidly, and with evolution of heat.

Acetone vapour is decomposed at a red heat into charcoal and *dumasine*, a peculiar empyreumatic oil. Passed over potassium hydrate at a red heat it forms marsh gas and carbonic acid—

$$\overset{\text{Acetone.}}{C_3H_6O} + \overset{\text{Potassium hydrate.}}{2KHO} = \overset{\text{Potassium carbonate.}}{K_2CO_3} + \overset{\text{Marsh gas.}}{2CH_4};$$

or at a lower temperature the products are as below—

$$\overset{\text{Acetone.}}{C_3H_6O} + \overset{\text{Potassium hydrate.}}{2KHO} + \overset{\text{Water.}}{H_2O} = \overset{\text{Potassium acetate.}}{KC_2H_3O_2} + \overset{\text{Potassium formate.}}{KCHO_2} + \overset{\text{Hydrogen.}}{6H}.$$

ALCOHOL.—*Hydrate of Ethyl; Ethyl alcohol, Hydroxyl ethane, Methyl carbinol.—Alcool*, French; *weingeist*, German; *spiritus rectificatus*, Pharmacopœia.

$$C_2H_6O = C_2H_5,HO = \left\{\begin{array}{l}CH_3\\CH_2\\HO\end{array}\right. = C\left\{\begin{array}{l}CH_3\\H\\H\\HO\end{array}\right. \text{or}$$

hydrated ethene (ethylene) C_2H_4,H_2O.

The word alcohol, derived from the Arabic *al kohol*, signifying a trituration or grinding, was at first applied to the preparation of antimony used by oriental women for painting their eyebrows. The appellation was afterwards given to other fine powders, and to highly-rectified spirits, but for what reason is not very clear.

There is no evidence of the ancients being acquainted with alcohol or ardent spirits; in fact, there is every reason to believe the contrary, and that even distillation was quite unknown to them. The method followed by Dioscorides to obtain quicksilver from cinnabar—sulphide of mercury—was really a process of distillation: he mixed the cinnabar with iron filings, put the mixture into a pot, to the top of which a cover of stoneware was luted; heat was applied, and when the process was terminated, the mercury was found adhering to the side of the cover. Dioscorides possessed much penetration and judgment, but he was unacquainted with the method of adapting a receiver to his pot, or he would not have proceeded as above recounted. Another strong corroboration of the fact, that alcohol was unknown in former times, is that neither the poets, historians, naturalists, nor medical men, make the slightest allusion to ardent spirits.

This compound, though viewed in many different aspects, as its varying formulæ denote, may be regarded as an atom of water (H_2O) in which half the hydrogen is replaced by ethyl (C_2H_5), *i.e.*, a compound of the radicle hydroxyl (HO) with the radicle ethyl ($C_2H_5 + HO = C_2H_6O$).

In the strict chemical sense, the term *alcohol* is employed as a generic name for a class of bodies belonging to the same type, or framed upon the same principle. Just as *salt*, originally applied to chloride of sodium, or the condiment with which we season our food, is now extended to a class of bodies often destitute of any savour; as *metal* designates several substances which do not possess either the malleability, the specific gravity, or the power of resisting heat which characterized those from which the term was borrowed; or as *acid* appertains to many compounds having neither a sour taste nor any caustic properties; so *alcohol* indicates a class, some members of which, far from being volatile, are not even liquid, and instead of igniting easily, require an elevated temperature for kindling.

All neutral compounds of carbon, hydrogen, and oxygen which react directly upon acids, so that water is eliminated and ethers are produced, are now termed alcohols.

Alcohols are formed from hydrocarbons by the substitution of one equivalent of the radical hydroxyl for one atom of hydrogen, in the case of monatomic alcohols, of two equivalents in the case of diatomic, three equivalents for triatomic alcohols, &c. These are generally spoken of as monatomic and polyatomic alcohols.

The chief monatomic alcohols are the following:—From methane or marsh-gas (CH_4) methyl alcohol is constituted thus: CHHH(HO)—

		Termed by Kolbe.	
Methyl alcohol,..................	$CH_4O = CHHH(OH)$	Carbinol,............	$C(OH)H_3$.
Ethyl alcohol, ...	$C_2H_6O = CHH(CH_3)(OH)$	Methyl carbinol, ...	$C(OH)H_2(CH_3)$.
Propyl alcohol,....................	$C_3H_8O = CHH(C_2H_5)(OH)$..........	Ethyl carbinol,......	$C(OH)H_2(C_2H_5)$.
Butyl or quartyl alcohol,.........	$C_4H_{10}O = CHH(C_3H_7(OH)$	Propyl carbinol,.....	$C(OH)H_2(C_3H_7)$.
Amyl or quintyl alcohol, ...	$C_5H_{12}O = CHH(C_4H_9)(OH)$.		
Sextyl alcohol, ...	$C_6H_{14}O = CHH(C_5H_{11})(OH)$.		
Septyl alcohol, ...	$C_7H_{16}O = CHH(C_6H_{13})(OH)$.		
Octyl alcohol, ...	$C_8H_{18}O = CHH(C_7H_{15})(OH)$.		
Nonyl alcohol, ...	$C_9H_{20}O = CHH(C_8H_{17})(OH)$.		

Alcohols are divided into groups, which are termed respectively primary, secondary, or tertiary, according as the carbon atom combining with the atom of hydroxyl is in combination with one, two, or three other carbon atoms.

Kolbe's nomenclature is convenient for the expression of the isomeric alcohols formed by the substitution of atoms of methyl, ethyl, propyl, &c., for the hydrogen atom in the group, which he terms carbinol (methyl alcohol). In this way we have:—

Dimethyl carbinol (isopropyl alcohol), $C(OH)H(CH_3)_2$
Isopropyl carbinol (isoquartyl alcohol) $C(OH)H_2CH(CH_3)_2$
Methyl-ethyl carbinol (secondary quartyl alcohol), $C(OH)H(CH_3)(C_2H_5)$
Trimethyl carbinol (tertiary quartyl alcohol) $C(OH)(CH_3)_3$

Methyl alcohol has already been considered. (See Acetic Acid.)

Ethyl alcohol is the most important of all these compounds. It was known to the alchemists. Its discovery is said to be due to Albucasis and Arnold de Villeneuve, in the twelfth century. Raymond Lully, about the fourteenth century, was acquainted with spirits of wine, which he called *aqua ardens*, and made by distilling wine and concentrating the distillate by means of potassium carbonate. Lœwitz and Richter subsequently succeeded in completely separating the water by means of quicklime. Alcohol was first analyzed by De Saussure, who separated it into 100 parts by weight of olefiant gas and 63·58 of water: about equal volumes of olefiant gas (ethane, C_2H_4) and aqueous vapour (H_2O). The vapour density of alcohol, as given by Gay Lussac, agrees with this composition.

In a general and practical sense, by *alcohol* is un-understood the pure spirit obtained by the distillation of liquids which have undergone vinous fermentation. It is the intoxicating principle of all vinous and spirituous liquors, as wine, brandy, whiskey, &c. Distilled from wine, it bears the name *spirit of wine.*

After the completion of fermentation distillation of the fermented body affords it either in a more or less concentrated state. Mere distillation, however, will not yield absolute alcohol, that is, alcohol free from water. For though absolute alcohol boils at 173° Fahr. (78°·4 C.), it has a great affinity for water, and dilution by water contracts its volume and raises its boiling point, so that the aqueous vapour corresponding to this temperature passes over with the spirit. At the lowest temperature at which the distillate is drawn off some aqueous vapours rise with the alcohol, and both are condensed simultaneously in the receiver; therefore, whatever the heat may be, the resulting alcohol is not anhydrous, but exhibits a density of 0·820 to 0·830.

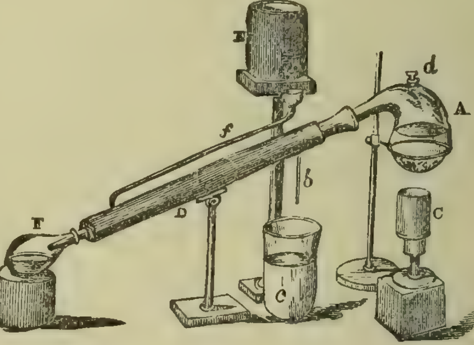
To procure absolute alcohol is a difficult and tedious operation: spirit of wine has to be distilled at a moderate heat from some hygrometric substance, such as anhydrous copper sulphate, calcium chloride, potassium carbonate, or quicklime. The best adapted for the purpose is quicklime reduced to coarse powder and put into a retort with the alcohol, and the whole mixed by agitation; the neck of the retort is then securely corked, and the mixture left for several days, during which period the water unites with the quicklime and converts it into calcium hydrate (CaH_2O_2), leaving the anhydrous spirit, which may be distilled off from the mixture by the heat of a water-bath.

Fig. 1 is the apparatus usually employed in the laboratory for this purpose: A is a glass retort; heat is applied by the lamp, C; D is a Liebig's condenser, through which the tube receiving the beak of the retort passes to the flask, F. Cold water from the tank, E, enters the condenser, D, by the funnel tube, *f*, and the heated water is discharged by *b* into the vessel, *c*. The mouth of the receiver is closed by a perforated cork, to prevent the access of air and the absorption of aqueous vapours. The dilute alcohol and coarsely-powdered dehydrating substance are introduced through the stoppered opening, *d*, the stopper replaced, and the distillation carried on at as low a temperature as possible—173° to 176° Fahr. (78° to 80° C.). Repeated distillations with fresh portions of the hygroscopic substance used are necessary to free the alcohol completely from water

To enable the quicklime to abstract all the water it should be left in contact with the alcohol for at least three or four days at the temperature of 95° Fahr. (35° C.): 1 part of 91 per cent. alcohol requires somewhat more than 1 part of quicklime in order to yield alcohol of 99·2 per cent. by filtration, and absolute alcohol by slow distillation. Alcohol of 94 per cent. requires only $\frac{5}{8}$ part of lime, and alcohol of 97 per cent. only $\frac{5}{16}$ of a part.

Mendelejeff states that to obtain the alcohol absolute, spirit of not more than ·792 specific gravity must be taken, and its digestion over the quicklime continued for not less than two days, or else for a few hours at between 122° to 140° Fahr. (50° to 60° C.). Even then, on distilling he found only the middle portions anhydrous.

Fig 1.



By boiling the spirit with the lime in a vessel fitted with an inverted condenser for about an hour, and then distilling, the whole product is obtained anhydrous. If the spirit contains more than 5 per cent. of water it is necessary to repeat the treatment with lime two or more times. But with weak spirit care must be taken at first not to fill more than half the space occupied by the spirit with lime, as otherwise the vessel may be broken by the slaking of the lime. In this way several litres of spirit may be converted into absolute alcohol in a few hours.

A singular mode of concentrating alcohol has been proposed by Soemmering. He used an ox or a calf bladder, which was soaked for some time in water, and freed from the fat and the attached vessels. After being again inflated and dried, it was coated, the outside twice and the inside four times, with a solution of isinglass, and then charged with diluted spirit, leaving a small space vacant. On exposing it to heat the water evaporates, while the alcohol remains. The bladders can be repeatedly used. It is stated that by this means, with proper attention to the degree of heat applied, absolute alcohol may be obtained in from six to twelve hours. Soemmering states that he placed two bladders of the same size, having eight ounces of water in one and eight ounces of absolute alcohol in the other, over a sand-bath, where equal heat was communicated to both; after the lapse of four days all the water was evaporated and only one ounce of the alcohol. Smugglers, who carry spirits in bladders hid about their persons, have often said that although the liquor decreased in bulk yet it increased in strength.

Donovan, Stanford, and others, have repeated these experiments without being able to obtain these results to the extent specified, if, indeed, at all. The alcohol was used of various strengths, with small and large bladders, with thick ones and thin ones; but a diminution of strength was the invariable result, unless the spirit was very weak, when a very slight increase of strength took place.

Graham repeated Soemmering's experiment with better success. He found that when a jar filled with alcohol was covered with a dry membrane the alcohol escaped first; but when a moist bladder was completely filled with dilute alcohol the liquid decreased in bulk, and the water passed through the membrane, leaving a much larger percentage of alcohol in the bladder. Graham believed that Soemmering's experiment was an instance of arrested diffusion when more that 5 per cent. of alcohol was present; the action having some resemblance to the separating and secreting power of cells in the living organism.

Graham proposed to concentrate alcohol in the following manner:—A large shallow basin is covered to a small depth with recently-burned lime, in coarse powder, and a smaller basin, containing three of four ounces of commercial alcohol, is made to rest upon the lime; the whole is placed under the receiver of an air-pump, and exhaustion continued till the alcohol evinces signs of ebullition. Of the mingled vapours of alcohol and water which now fill the receiver, the quicklime is capable of uniting with the aqueous only, which are, therefore, rapidly withdrawn, while the alcohol vapour is unaffected; and as water cannot remain in the alcohol as long as the surrounding atmosphere is devoid of moisture, more aqueous vapour rises, which is likewise abstracted by the lime, and thus the process goes on till the whole of the water in the alcohol is removed. Several days are always required for this purpose, and in winter a longer time than in summer. On submitting alcohol of spec. grav. 0·827 to dehydration by this method, the following are the notes of the decreasing specific gravity after every twenty-four hours:—

When the liquid was introduced, the density was	0·827
Density after twenty-four hours' exposure to the action of the caustic lime, ...	0·817
Do. after second twenty-four hours,........	0·808
Do. after third do.	0·802
Do. after fourth do.	0·798
Do. after fifth do.	0·796

The longer time required for the concentration of the spirit in the winter season is seen from the following table, where the liquid, before inclosing it under the air-pump with the lime, had a spec. grav. 0·825:—

On determining the specific gravity after twenty-four hours, the result was, ...	0·817
Do. after the second twenty-four hours, ...	0·809
Do. after the third do.	0·804
Do. after the fourth do.	0·799
Do. after the fifth do.	0·797
Do. after the sixth do.	0·796

Quicklime possesses the property of uniting with a portion of alcohol vapour, and for this reason should not be used in great excess. Graham found that when four ounces of ordinary alcohol were exposed to the action of the lime, under the bell-jar of the air-pump, one-sixth of the alcohol was lost, on account of the absorption by the quicklime. Liebig states that in dehydration by lime half this alcohol is retained by the lime, but can be recovered by distillation. Hence the quantity of lime used should never exceed three times the weight of the alcohol, otherwise the loss of alcohol will become appreciable; the lime should be spread to as great an extent within the receiver as possible, that a larger absorbing surface may be presented to the vapour.

Connell states that if the lime be renewed every week the alcohol continues to lose water, becoming in four weeks of the density 0·795 at 60° Fahr. (15°·5 C.), and in twelve weeks becomes absolute alcohol; spec. grav. 0·7938.

Alcohol may also be concentrated by exposing it with lime in a close vessel. It cannot be concentrated over strong sulphuric acid, for this acid absorbs alcohol vapour with the same affinity with which it unites with water, the heat produced being very great; ethionic acid (C_2H_6,S_2O_7), a bibasic acid, is formed by this reaction. Calcium chloride is not well adapted for concentrating alcohol, on account of the affinity existing between these two bodies; since, if employed in excess, it forms a compound with alcohol which is not decomposed till a temperature is reached at which the alcohol is split up into olefiant gas (C_2H_4) and water; also, when submitted to distillation, the aqueous vapour absorbed by the chloride of calcium is apt to go over with the last portions of the alcohol, through the salt settling at the bottom of the retort and becoming over heated.

An excellent method for the preparation of pure alcohol was devised by Poggendorff.—Dissolve as much caustic potash in alcohol as it will take up, then add half its volume of water, and distil at a low temperature; a perfectly pure product is the result.

Drinkwater, in his investigation on the preparation of absolute alcohol and the composition of *proof spirit*, procured alcohol of the lowest specific gravity hitherto obtained. His mode of procedure was as follows:—Potassium carbonate was exposed to a red heat, to deprive it of water, and when sufficiently cool was pulverized and added to ordinary alcohol, of spec. grav. ·850, at 60° Fahr. (15°·5 C.), till it ceased to dissolve any more; the menstruum was then allowed to digest twenty-four hours, being frequently agitated, and the alcohol carefully separated by decantation. As much fresh-burned quicklime as was considered sufficient, when powdered, to absorb the whole of the alcohol, was introduced into a retort, and the alcohol added to it; after digesting forty-eight hours, it was slowly distilled into a water-bath at a temperature of about 180° Fahr. (82° C.).

The alcohol thus obtained was carefully redistilled, the retort again filled with fresh-burned and pulverized quicklime, and the same alcohol mixed with it; the mixture was then allowed to digest a whole week, at the ordinary temperature of the laboratory.

After this lapse of time, the alcohol was distilled off as before, and the distillate submitted to a second operation, which was conducted at first at the rate of about one drop in ten seconds, the heat of the water-bath being 165° Fahr. (74° C.). The distillation was continued thus till about one-twentieth of the whole had passed over, the object being to allow any minute quantity of water which the alcohol might still retain, to evaporate or diffuse itself into the atmosphere of absolute alcohol above it; the process was then continued rapidly, the heat of the bath being increased to 180° Fahr. (82° C.), till about one-twentieth more had passed over; the receiver was then changed, and the latter portions slowly eliminated. The specific gravity of the alcohol, taken twice, was ·7944, at 60° Fahr. This alcohol was again digested at a temperature of about 150° Fahr. (65°·5 C.) for fourteen days with quicklime previously heated to redness, as in the former experiment; it was then slowly distilled, out of contact with the external atmosphere, by means of a tube which passed from the condenser through a cork into the bottle in which it was to remain—the temperature at which it was distilled being 175° Fahr. (79°·3 C.)—and the first tenth part put aside as possibly containing a minute quantity of water; the remainder was then distilled off at 178° to 180° Fahr. (80°·8 to 82° C.). This alcohol was quickly transferred to a dry retort, and redistilled in a similar way, at a water-bath heat of 172° Fahr. (77°·6 C.); the first tenth part was set aside, and the remainder kept as pure anhydrous alcohol, or as free from water as it is possible to obtain it by this process. The specific gravity was then taken, the alcohol being kept, during the time of transference, as much as possible out of contact with the air. The results of four trials were as annexed:—

Temp. of room, 60° Fahr. Barometer, 29·810 inches.

I.,	·793836
II.,	·793806
III.,	·793798
IV.,	·793804
Mean,	·793811

A portion of this alcohol was subsequently digested with quicklime for three months; it was then distilled, and its specific gravity was found to be exactly the same as before.

According to Kopp the specific gravity of alcohol is at 32° Fahr. (0° C.) 0·8095, at 60° Fahr. (15°·5 C.) 0·7939, at 68° Fahr. (20° C.) 0·792. The boiling point of alcohol is 173·1 Fahr. (78·4 C.) under the pressure of 760 mm.—Gay Lussac. The same chemist places its vapour density at 1·613 as compared with air, and 23·27 as compared with hydrogen.

Properties of Alcohol.—Pure anhydrous, or absolute alcohol, is a limpid colourless liquid, of a greater fluidity than water, having a penetrating but agreeable odour, and a hot pungent taste, owing to its abstracting water from the tissue of the tongue. When undiluted it exercises a poisonous action on the system, since it destroys the vital functions of the tissues by abstracting their constitutional moisture, by reason of its own great affinity for water. These violent effects are not produced when alcohol is taken in small quantities in a diluted state. It is a powerful stimulant and antiseptic.

Alcohol, when anhydrous, burns with a whitish flame, which deposits carbon on a cold surface held in it; when it is mixed with water the flame is quite blue, and no deposit of carbon is formed. In the combustion of alcohol very little light is emitted, but intense heat is given off: Boerhaave first showed that when its products of combustion are collected in proper vessels, water constitutes a large part of them.

Alcohol is exceedingly volatile: if a few drops be introduced into a jar of oxygen gas, it is readily converted into vapour, and a very explosive mixture is produced. When one volume of alcoholic vapour and three of oxygen are mixed, and ignited by the electric spark, a violent explosion ensues, and two volumes of carbonic acid and three volumes of aqueous vapour are formed.

When the sparks from an induction coil are passed through liquid alcohol it soon acquires an acid reaction, deposits black flocks, gives off gas, and forms a resinous substance. Addition of a small quantity of potassium hydrate facilitates the reaction. The evolved gases are similar in composition to that which is produced by the decomposition of alcohol by heat. —A. Quet.

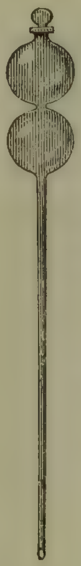
Perrot states that when the electric sparks are passed for a long time through alcohol vapour, the alcohol is at length completely decomposed into a gas (containing no ethylene, but which is absorbed by bromine) and a solid residue consisting of charcoal, with a trace of resinous matter. The bromine solution of the gas is colourless, has a sweet taste, and an odour somewhat similar to that of chloroform.

Alcohol has never been solidified. Faraday exposed alcohol to a temperature of 160° Fahr. below zero; it thickened, but did not congeal. Hence the great use of spirit thermometers when a very low temperature is required to be noted.

Faraday obtained this exceedingly low temperature by the following means. He prepared a bath of Thilorier's mixture of solid carbonic acid and ether in an earthenware dish, of the capacity of about 4 cubic inches, which was fitted into a similar dish somewhat larger, with three or four folds of dry flannel intervening. Such a bath will retain the carbonic acid in a solid state for about twenty minutes. To procure a still lower degree of cold, the bath of carbonic acid and ether was put into an air pump, and the air and gaseous carbonic acid rapidly removed. Operating in this way, the temperature fell so low that the vapour of carbonic acid given off by the bath, instead of having a pressure of one atmosphere, had only a pressure of $\frac{1}{24}$th of an atmosphere, or 1·2 inches of mercury, for the air pump barometer could be kept at 28·2 inches when the ordinary barometer was 29·4. At this low temperature the carbonic acid mixed with the ether was not more volatile than water at the temperature of 86° Fahr. (30° C.), or alcohol at ordinary temperatures.

Alcohol has a powerful affinity for water; hence the necessity of keeping it in ground stoppered bottles. When mixed with water, much heat is produced, and a diminution in volume takes place. This may be shown by mixing the two liquids in the apparatus shown at Fig. 2—which consists of a long tube of glass, furnished with two bulbs on the upper part, and having the elongated neck of the higher bulb closed perfectly with a ground glass stopper. The tube and lower bulb are filled with distilled water; when this is effected, alcohol is poured in till the upper bulb is filled; the stopper is next replaced, and the tube gently inverted. The two liquids now combine, and in the tube an empty space is visible, which before combination was completely filled. The space unoccupied shows the amount of contraction in bulk which has arisen from the combination of the alcohol and water; an elevation of temperature also takes place, in consequence of the chemical combination and the diminished specific gravity of the mixture. Thus, equal measures of alcohol, of spec. grav. 0·825, and water, each at 50° Fahr. (10° C.), when suddenly mixed, rise to the temperature of 70° (21° C.); and a mixture of equal parts of proof spirit and water, at 50° Fahr. (10° C.), give, under the like circumstances, a mixture having a temperature of 60° Fahr. (15°·5 C.) When alcohol and ice are mixed, the temperature is considerably reduced. Absolute alcohol, with a little more ice than it will dissolve, reduces the temperature as low as —35° Fahr. (—37°·2 C.). Spirit of wine, of spec. grav. 0·86, and 61° Fahr. (16° C.) temperature, mixed with snow at 32° Fahr. (0° C.), is cooled down to —14° Fahr. (—25°·5 C.). The contraction arising from the admixture of alcohol and water, increases regularly till the liquid consists of nearly one atom of alcohol and three atoms of water ($C_2H_6O + 3H_2O$), or 52·3 volumes of alcohol and 47·7 volumes of water, which in mixing contract to 96·35 volumes; hence the contraction is 3·65 volumes.

Fig. 2.



Thillaye shows that the mixture, when water is present beyond a certain limit, expands sensibly; his experiments also prove, besides, that when three volumes of alcohol, of spec. grav. 0·964, are mixed with seven of water, the mixed solution has a spec. grav. of 0·9850, whereas the calculated specific gravity should be 0·9863, thus indicating a decrease of gravity and a corresponding increase of volume, amounting to ·0013. This expansion, however, is only apparent, on account of the heat which is generated; but if the mixture were made of absolute alcohol and water till the specific gravity became 0·985, instead of an expansion, a contraction of 0·007 would be observed.

The following table, from the calculation of **Gay-Lussac**'s experiments by **Rudberg**, shows the contraction of every decreasing 5 per cent. in the content of alcohol:—

Per cent., in volume, of absolute alcohol in 100 volumes of mixture at 59°.	Contraction, in per cent., of the volume of the mixture.	Per cent., in volume, of absolute alcohol in 100 volumes of mixture at 59°.	Contraction, in per cent., of the volume of the mixture.
100	0·00	50	3·74
95	1·18	45	3·64
90	1·94	40	3·44
85	2·47	35	3·14
80	2·87	30	2·72
75	3·19	25	2·24
70	3·44	20	1·72
65	3·61	15	1·20
60	3·73	10	0·72
55	3·77	5	0·31

From this table it will be observed, that the contraction is the same with mixtures containing different amounts of alcohol; for example, with the mixture containing 70 per cent. of alcohol and that containing 40 per cent. the contraction is 3·44. The reason is evident: the contraction increases to a certain point, and then decreases as the proportion of absolute alcohol lessens, giving to the intermediate mixtures, between the maximum and minimum points, a corresponding degree.

The volatility of alcohol is generally affected by admixture with water, as well as its specific gravity and expansive force. **Tralles** found that small quantities of water mixed with alcohol do not sensibly raise the boiling point of the liquor beyond that of pure alcohol; and **Soemmering** has shown that a mixture of alcohol with about 3 per cent. of water has greater volatility than absolute alcohol, and that a spirituous liquor compounded of 94 per cent. of absolute alcohol and 6 of water, possesses the same volatility as alcohol of 0·7947. Further, according to **Soemmering**, when alcohol of 0·7947 density is mixed with water till the specific gravity becomes 0·8, and distilled, those portions which first pass off are saturated with water, and the alcoholic solution in the retort becomes richer, till, in the end, absolute alcohol passes over; on the contrary, when the mixture contains over 6 per cent of water, the first portions of the distillate are richest in alcohol, and afterwards they become weaker to the end of the operation. The temperature also rises as the alcohol is expelled, gradually approaching to that of boiling water, and actually attaining that point at the close of the process, when all the spirit is driven over.

Taking advantage of this property, an attempt has been made to give the strength of various mixtures of alcohol and water, by ascertaining the temperature of the vapour, for which purpose **Groening** has constructed the following table. It consists of three columns: the first shows the temperature; the second, the quantity of alcohol in the boiling solution; and the third, the quantity of alcohol in the vapour evolved:—

Temp. Fahr.	Per cent. of alcohol in the boiling liquid in the retort.	Per cent of alcohol in the distillate.	Temp. Fahr.	Per cent. of alcohol in the boiling liquid in the retort.	Per cent. of alcohol in the distillate.
171°	92	93	189°·5	20	71
171·4	90	92	191·8	18	68
172	85	91·5	194	15	66
172·7	80	90·5	196·3	12	61
173·8	75	90	198·5	10	55
175·1	70	89	200·8	7	50
176	65	87	203	5	42
178·3	50	85	205·3	3	36
180·5	40	82	207·5	2	28
182·8	35	80	209·8	1	13
185	30	78	212	0	0
187·3	25	76			

The elastic force of alcohol vapour is very great; the following table shows the elastic force from 32° to 264° Fahr. (0°·0 to 128°·8 C.). The specific gravity of the alcohol was 0·813.

Temperature.		Force of vapour.	Temperature.		Force of vapour.	Temperature.		Force of vapour.
Cent.	Fahr.		Cent.	Fahr.		Cent.	Fahr.	
0°·0	32°	0·40	57°·2	135°	12·15	102°·2	216°	72·20
4°·4	40	0·56	60°·0	140	13·90	104°·4	220	78·50
7°·2	45	0·70	62°·7	145	15·95	107°·2	225	87·50
10°·0	50	0·86	65°·5	150	18·00	110°·0	230	94·10
12°·7	55	1·00	68°·3	155	20·30	111°·1	232	97·10
15°·5	60	1·23	71°·1	160	22·60	113°·3	236	103·60
18°·3	65	1·49	73°·8	165	25·40	114°·4	238	109·90
21°·1	70	1·76	76°·6	170	28·30	115°·5	240	111·24
23°·8	75	2·10	78°·3	173	30·00	117°·7	244	118·20
26°·6	80	2·45	81°·1	178	33·50	118°·4	247	122·10
29°·4	85	2·93	82°·2	180	34·73	120°·0	248	126·10
32°·2	90	3·40	83°·3	182	36·40	121°·1	250	132·30
35°·0	95	3·90	85°·0	185	39·90	122°·2	252	138·60
37°·7	100	4·50	87°·7	190	43·20	123°·3	254	143·70
40°·5	105	5·20	89°·4	193	46·60	125°·5	258	151·60
43°·3	110	6·00	91°·1	196	50·10	126°·6	260	155·20
46°·1	115	7·10	93°·3	200	53·00	127°·7	262	162·40
48°·8	120	8·10	96°·6	206	60·10	128°·8	264	166·10
51°·6	125	9·25	98°·8	210	65·00			
54°·4	130	10·60	101°·1	214	69·30			

The expansion of alcohol by heat is not uniform; 1000 measures, spec. grav. 0·817, become 1079 when heated from 50° to 170° Fahr. (10° to 76°·6 C.). At a medium temperature the expansion is a little below the true mean; but with the state of dilution of the alcohol this difference between both ends of the scale becomes more marked. The greatest uniformity of expansion is between —14° and +98° Fahr. (—25°·5 and 36°·6 C.), being about 0·00047 of its volume for every degree. The contraction of alcohol from its boiling point, 173°·1 Fahr., has been investigated by GAY-LUSSAC, who gives the condensation of 1000 volumes in every 9° Fahr., or 5° C., from the boiling point of the liquid.

Temperature.		Volume of alcohol.	Temperature.		Volume of alcohol.
Centigrade.	Fahrenheit.		Centigrade.	Fahrenheit.	
78°·4	173°·1	1000·0	38°·3	101°	954·3
73°·3	164	994·4	33°·3	92	949·1
68°·3	155	988·6	28°·3	83	944·0
63°·3	146	982·5	23°·3	74	939·0
58°·3	137	975·7	18°·3	65	934·0
53°·3	128	970·8	13°·3	56	929·3
48°·3	119	965·3	8°·3	47	924·5
43°·3	110	969·7	3°·3	38	919·9

One volume of alcohol yields 488·3 volumes of vapour at 212° Fahr. (100° C.); compared with water at the same temperature, the volume of alcoholic vapour is greater in the ratio of 3·14 to 1·00.

Alcohol vapour, when transmitted through a red-hot porcelain tube, is decomposed. SAUSSURE found that, on passing it slowly through a porcelain tube heated to redness, a little carbon was deposited on the interior of the tube, together with a volatile crystalline substance — naphthaline — and a brown empyreumatic oil; the gaseous products were carbonic oxide, carbonic acid, hydrogen, marsh gas, olefiant gas, and aqueous vapour. M. BERTHELOT passed alcohol vapour through a porcelain tube filled with pumice, and heated to redness. He obtained carbon, hydrogen, marsh gas, olefiant gas, aldehyde, naphthaline, benzol, phenyl hydrate, and (?) acetic acid.

The analysis of alcohol by SAUSSURE, DUMAS, and others, shows that it consists of—

	Atomic weight.	Per cent.
2 Eqs. of carbon, ...	24	52·18
6 Eqs. of hydrogen, ...	6	13·04
1 Eq. of oxygen, ...	16	34·78
	46	100·00

Formula:—C_2H_6O.

Alcohol possesses the property of absorbing gases in even a higher degree than water. Many experiments have been made by SAUSSURE on this subject, from whose results the following table has been formed:—

Absorbed at 64°·4 Fahr. (18° C.).	By 1 volume air-free water.	By 1 volume air-free alcohol. sp. gr. 0·84.
	Volumes.	Volumes.
Sulphurous acid gas, ...	43·78	115·77
Sulphuretted hydrogen, ...	2·53	6·06
Carbonic acid, ...	1·06	1·86
Nitrous oxide, ...	0·76	1·53
Olefiant gas, ...	0·155	1·27
Oxygen, ...	0·065	0·1625
Carbonic oxide, ...	0·062	0·145
Hydrogen, ...	0·046	0·051
Nitrogen, ...	0·042	0·042

Alcohol absorbs about 68 volumes of hydrochloric acid gas; it also takes up considerable quantities of cyanogen and nitric oxide. Most of these gases are evolved when the saturated spirit is boiled or exposed to the air, while others, such as hydrochloric acid gas, nitrous acid, &c., decompose the liquid.

Strong alcohol is one of the best solvents which the chemist possesses; by dilution with water this property is much diminished. Sulphur is dissolved by it when hot; but is deposited again in small crystals as the solution cools. An alcoholic solution of sulphur becomes turbid when diluted with water, and evolves a peculiar hepatic odour, and like the soluble sulphides precipitates metals as sulphides. Phosphorus is also dissolved by alcohol, for which purpose BUCHNER states that 320 parts of cold and 240 part of hot alcohol are required. From the latter solution one-fourth of the quantity of phosphorus deposits as it cools.

Alcohol absorbs chlorine gas with great avidity; it loses part of its hydrogen, which is replaced by the chlorine, forming hydrochloric acid, aldehyde, acetic acid, ethyl acetate, ethyl chloride, and chloral. When the action is long continued this last substance is the principal product.

$$\begin{array}{ccccc} \text{Alcohol.} & & \text{Hydrochloric acid.} & & \text{Chloral.} \\ C_2H_6O + 4Cl_2 & = & 5HCl & + & C_2HCl_3O. \end{array}$$

With bromine it acts in a similar manner, forming bromal and hydrobromic acid. The heat evolved in these reactions often causes the alcohol to take fire.

Iodine is dissolved by alcohol, and forms a brown coloured solution; if hot alcohol be employed, the iodine is deposited in crystals after some time, and hydriodic acid is formed in the liquid. If to a solution of iodine in alcohol, an alcoholic solution of potassium hydrate be added, the fluid becomes colourless, and iodide of potassium and iodoform are simultaneously produced,

By a corresponding decomposition, when distilled with hypochlorite of lime, or bleaching powder, alcohol gives rise to choloform.

$$\begin{array}{ccccccc} \text{Ethyl alcohol.} & & \text{Calcium hypochlorite.} & & \text{Chloroform.} & & \\ 2C_2H_6O & + & 5CaCl_2O_2 & = & 2CHCl_3 & + & \end{array}$$
$$2CaCO_3 + 2CaCl_2 + CaH_2O_2 + 4H_2O.$$

Concentrated chloric, bromic, and nitric acids react violently upon alcohol, producing acetic acid and a number of other bodies. This reaction is sometimes so energetic as to cause combustion. A mixture of very weak sulphuric acid and peroxide of manganese, when distilled with spirit of wine, yields principally aldehyde; acetic and formic ether are also formed, and towards the end of the distillation a weak solution containing acetic and formic acids passes over.

Pure chromic acid acts upon alcohol, giving rise to aldehyde and chromium sesquiacetate. Sulphuric acid, with moderately dilute alcohol, gives rise to ether, as also do phosphoric and arsenic acids; even selenious acid, on being distilled with that liquid, causes the formation of ether. On distilling a mixture of selenious acid, sulphuric acid, and alcohol, the distillate emits a most horrible odour; evolving hydro-selenic acid (selenetted hydrogen, H_2Se), and selenium deposits in the retort. Acetic, oxalic, formic, hydrochloric, hydrobromic, and hydriodic acids decompose alcohol, giving rise to ethers. Chloride of antimony, sesquichloride of iron, bichloride of tin, &c., decompose alcohol, forming oxides and hydrochloric ethers. Potassium behaves with alcohol as with water.

Graham has shown that alcohol combines with most salts, forming with them peculiar compounds, alcoholates, analogous to hydrates. A great many of the neutral salts are soluble in alcohol; in general, all deliquescent salts, excepting the carbonate of potassa, are soluble in alcohol, and those inorganic compounds which are only sparingly soluble in water also prove insoluble in that liquid.

Alcohol is peculiarly adapted for dissolving copal, mastic, and a great number of resins which are employed in the preparation of the finest varnishes. The fats and volatile essential oils are likewise dissolved by it, and are employed with balsams in the composition of an extensive class of tinctures.

Anhydrous alcohol completely stops the current of a weak voltaic battery. Connel states that if two parallel platinum plates be introduced as electrodes into alcohol of spec. grav. 0·790, at 68° Fahr. (20° C.), their surfaces being $\frac{1}{40}$th of an inch apart, and the current of a battery of 216 pairs of 4-inch plates made to act on the liquid, no gas is evolved, but a little resin deposited at the positive pole, whilst pure hydrogen escapes very slowly at the negative pole. Lüdersdorff found that alcohol of spec. grav. 0·789 acted in a similar way under the influence of a powerful electric current.

The more dilute the alcohol, the less resistance does it offer to the passage of the current, and the greater is the quantity of hydrogen evolved at the negative pole; when the quantity of water present is comparatively large, oxygen is likewise evolved at the positive pole. Aldehyde, acetic acid, and other products of decomposition are produced at the same time.

The imperfect combustion of alcohol by means of platinum has already been noticed (see Acetic Acid). When platinum black is shaken on paper moistened with strong alcohol, it makes a hissing noise, and becomes red hot, and if it does not set fire to the alcohol, continues to glow, and produce acetic acid as long as there is any alcohol.—Edmund Davy. If the platinum black be first moistened with water or alcohol, the ignition of the alcohol is prevented, and it is entirely converted with evolution of heat into acetic acid.—Döbereiner.

Sir Humphrey Davy discovered that a fine platinum wire, heated to redness, and held in the vapour of ether, continued ignited for some time. Mr. Gill has practically applied this discovery in the formation of an alcohol lamp—lamp without flame—of the following construction:—A cylindrical coil of thin platinum wire is placed, part round the cotton wick of a spirit lamp, and part above the wick, and the lamp lighted to heat the wire to redness; on the flame being extinguished the alcoholic vapour keeps the wire red-hot for any length of time, according to the supply of the spirit, and with a very small expenditure thereof, so as to be in constant readiness to ignite tinder or a lucifer match. The proper size of the platinum wire is the hundredth part of an inch, which may be easily ascertained by coiling ten turns of the wire on a cylinder, and if they measure the tenth of an inch it will be right. A larger size only yields a dull red light, and a smaller one is difficult to use; about twelve turns of the wire will be sufficient, wrapped round any cylindrical body suited to the size of the wick of the lamp, and four or five coils should be placed on the wick, and the remainder of the wire above it.

A lamp constituted as above will require about half an ounce of alcohol to keep it in readiness for eight hours. This lamp affords sufficient luminousness to show the hour of the night by a watch, and to perform other useful services.

Alcohol, under the influence of concentrated sulphuric acid, may be converted, with the aid of heat, into water and olefiant gas ($H_2O_4 + C_2H_4 = C_2H_6O$). It was discovered by Hennel, and confirmed by Berthelot, that it is possible to reunite these bodies.

Faraday observed that sulphuric acid absorbed as much as 40 times its volume of olefiant gas. The resulting compound is sulphovinic acid, or as it is now termed, ethyl sulphuric acid ($C_2H_6SO_4 = H_2SO_4$, in which half the H is replaced by ethyl, C_2H_5). Hennel added water to this body, and on distilling the mixture obtained ethyl alcohol.

Berthelot dissolved 30 litres of pure olefiant gas in 900 grammes of pure and very concentrated sulphuric acid. He afterwards added to the sulphuric acid 5 or 6 volumes of water, filtered and distilled it; then again submitting the liquid to several successive distillations, and putting it, after each distillation, in contact with potassium carbonate, in order to separate the aqueous portion of the distillate, he obtained 52 grammes of an alcohol corresponding to 45 grammes of absolute alcohol, and representing three-fourths of the olefiant gas; the remainder was lost in the manipulations.

The alcohol thus formed possessed all the properties of ordinary alcohol—the same taste and spirituous odour, the same boiling point, the same inflammability and the same colour in the flame, the same solvent power, the same reaction on all bodies and formations of absolutely identical products.

Saytzeff endeavoured to convert acetic acid into ethyl alcohol by treating it with deoxidizing substances, but without success. He, however, turned his attention to acetic chloride, or acetyl chloride (C_2H_3OCl), as the only derivative that can be readily prepared from it in large quantity, and that more easily undergoes chemical changes than the acid itself.

For the conversion of acetic chloride into ethyl alcohol a substance had to be chosen which, in presence of sodium amalgam, evolved hydrogen without decomposing the acetic chloride. As such a body he employed glacial acetic acid, and by acting on a mixture of this substance and acetic chloride with solid sodium amalgam, he obtained ethyl alcohol in considerable quantity.

The conversion of this mixture of acetic chloride and acetic hydrate proceeds in this way:—The hydrogen generated by the action of the sodium amalgam on the acetic hydrate apparently changes the acetic chloride into aldehyde, which by the further action of hydrogen passes into alcohol; a fresh quantity of acetic chloride then converts the alcohol into acetic ether, which is the final product of the reaction. Along with this process another reaction occurs, whereby, at the expense of the acetic chloride and sodium acetate, acetic anhydride is formed, and this by the nascent hydrogen is also converted into alcohol, which, as in the first case, is obtained as acetic ether.

The operation is conducted in the following way:—Solid sodium amalgam, finely divided, and consisting of 100 parts of mercury and 3 parts of sodium, is placed in a flask fitted to the lower end of a condenser and immersed in ice water. To 1½ molecules of the sodium a mixture of 1 molecule of acetic chloride and 2 molecules of acetic hydrate is taken, and is gradually poured upon the amalgam, the contents of the flask being constantly agitated either by shaking or by a glass stirrer passed through the cork. After running in all the mixture the flask is kept in motion until its contents become a solid mass, when it is set aside for twenty-four hours. Water is then added and the mixture distilled until oily drops cease to come over with the water. The distillate consists of two layers, the upper of which has a strong odour of acetic ether. This is decomposed by concentrated potash solution; and an alcoholic fluid is then distilled off, which after rectification and drying is anhydrous ethyl alcohol.

Linnemann has obtained ethyl alcohol by acting on acetic anhydride with sodium amalgam. The acetic anhydride is added to an amalgam containing not more than 4 per cent. of sodium, with very great caution, avoiding both a rise of temperature and the hardening of the mass, which at the end of the operation should appear dry and dusty. It is then mixed with powdered ice or snow, when the amalgam deliquesces without evolution of gas. Water and a little more amalgam are then added, an oily matter is separated by filtration, and the mixture neutralized with solid potassium carbonate. The liquid is then rectified in the usual way, when pure ethyl alcohol results.

In those cases where it is desired to determine with certainty the existence of alcohol in presence of a large quantity of water, Berthelot recommends the following method. Benzoyl chloride (C_7H_5OCl) is decomposed very slowly by cold or lukewarm water; but if the water contains alcohol a benzoic ether is immediately formed; the ether is found with the excess of benzoyl chloride. The presence of the ether can be made manifest by heating a drop of the benzoyl chloride with aqueous solution of potash, which dissolves the acid chloride almost immediately, without acting at first on the ether. The reaction is very distinct with $\frac{1}{100}$th part of alcohol. Even with a $\frac{1}{1000}$th part of alcohol, the smell of the benzoic ether is very apparent when a few cubic centimètres of liquid are used.

Alcoholic Liquors—*Whisky; Usquebaugh; wysge*, a stream; *uisge-béatha*, water of life, Irish; *usqueba*, French; the spirit distilled from barley, rye, wheat, &c. The Latin epithet, *aqua vitæ*, the Irish term usquebaugh, and the modern word whisky, are in point of fact synonymous. The English, shortly after the invasion, in the time of Henry II., found the Irish people indulging in potations of this liquor. History informs us that the knowledge of *aqua vitæ* was first acquired in Europe in the reign of that monarch; but it is more than probable that the Irish were acquainted with it before the English. The strong similarity between the Irish language and the primitive languages of Asia, as stated by eminent etymologists, and the intercourse the Irish had with that quarter of the world, lead to the supposition that the art of distillation was introduced directly from India.

CAMPION relates, that when the new settlers were attacked by any of the diseases common to the country, they used *aqua vitæ*, or *usquebaugh*, the ordinary beverage of the inhabitants, as the best restorative of health.

The directions for making *aqua vitæ* or *usquebaugh*, and liquors compounded from it, are recorded in the Red Book of Ossory, a work compiled about 500 years since. *Aqua vitæ* was first issued as a medicine, and was considered as a panacea for all disorders; the physicians recommended it to patients indiscriminately, for preserving health, dissipating humours, strengthening the heart, curing colic, dropsy, palsy, &c., and even for prolonging existence itself beyond the common limits. Hence it was eagerly sought, and the taste, once formed, has been transmitted from generation to generation.

The excise duties have great influence on the mode of manufacture of spirits in this country. The system of supervision is a remarkable instance of excise machinery—a supervision rendered important by the great sum collected annually, considering the comparatively small number of distillers by whom the payments are made. As the duty per gallon is estimated on spirit of one particular degree of strength, the greatest caution is necessary in testing all the liquors produced, as a guarantee that every sample is charged exactly in proportion to its quantity and to its strength. Excise officers, as agents for the government, are almost constantly present at every distillation, day and night. They succeed each other, one or more at a time, as may be necessary, after intervals of eight hours; the periods being from six A.M. to two P.M.; from two P.M. to ten P.M.; and from ten P.M. to six A.M. of the following day. The Act of Parliament to regulate distilleries was passed in 1825, and by its provisions no distiller was permitted to work till he had procured a license, which was to be renewed yearly; moreover, he was not allowed to have on his premises a still below a certain capacity. The number of stills, charges, receivers, &c., continues subject to certain restrictions; and the exact routine is given as to the mode the liquid shall run from one vessel to another in the process of distillation. The openings in the principal vessels are expressly stated, and the most scrupulous care is taken that nothing shall pass from one vessel to another without traversing a pipe having a lock or valve, which is provided and kept in repair by the distiller, to the satisfaction of the excise officer, who has charge of the key, under a penalty of £200. This functionary also keeps the keys to lock up the furnace doors and stills; in fact, he exercises a perfect control over every operation and process; and with the view of facilitating his superintendence, the brewing and the distilling take place at different periods, one portion of time being set apart for the preparation of the *wash*, and another for its distillation.

In order that the intentions of the law may be fully carried out, prohibiting the synchronous brewing and distilling, the buildings are detached or conveniently divided, and the pipes, a large number of which are visible, are of various colours. The legislature requires that the conduit pipes shall be painted *black;* those for the conveyance of wash, *red;* those for the first distillate, *blue;* and those for the finished spirit, *white;* this is done in order that the officer may conveniently trace the routine of the processes; further, ladders and all other conveniences must be furnished for the easy access of the supervisor to all the vessels in the establishment.

The new Act specifies that no spirit receiver shall be used in any distillery, which shall not be made, placed, and fixed, to the satisfaction of the commissioners of Inland Revenue, and be sufficiently deep to admit of the gauge being taken of the depth of 15 inches in the centre; and every such receiver shall be so filled, that at the time of gauging the same, for the purpose of charging the duty thereon, the depth of the spirit shall not be less than 15 inches, under a penalty of £50.

The fabrication of ardent spirits is a very extensive branch of the home trade of this country. Whisky is the staple produce; gin, rum, brandy, &c., being made in other countries by operations analogous to those followed in the manufacture of whisky. Gin and rum are extensively manufactured in this country, but invariably from whisky.

The operations of a *distillery* relate to the extraction of the alcohol from various sorts of grain. Wheat, oats, barley, rye, Indian corn, rice, and other grains, whether in the raw or in the malted state, as well as the juices of fruits, sugar-cane, beet-root, potatoes, carrots, and even some of the *grasses*, and many other vegetable and natural substances, by peculiar processes are made to yield alcohol. Distillation is invariably one of these operations, but it is preceded by others which differ according to the nature of the ingredients employed.

Those universally known liquors, whisky, hollands, gin, brandy, rum, spirits of wine, and cordials of various kinds, all contain alcohol, which passes over in the process of distillation. British brandy, British gin, whisky, or rum, are produced from corn; French brandy, from wine; West Indian rum, from sugar or molasses. The different qualities of these various liquids depend partly on the percentage of alcohol contained, partly on the berries, herbs, and seeds with which they are flavoured, partly on their mode of manufacture, and lastly, on the substances whence they are derived. In every case, however, the substance distilled is a *sweet* liquid, though the means by which the saccharine material is formed vary with circumstances. The extract produced from grain is fermented before being distilled.

This liquor, modified in a particular way at the brewery, constitutes *beer;* in the distillery it is known under the name of *wash*, and is the liquid which undergoes, subsequently, the process of distillation.

The first objects that meet the eye in a large distillery are the magazines in which the grain is stored; beyond these are the various buildings connected with the still-room. Near the entrance are the mill and the brewhouse.

All the grain goes through the granary, and when required in meal, passes into the mill-room, which contains several pairs of millstones, worked by a large steam-engine. The meal next goes to the brewhouse, in which are large coppers for heating water, and prodigious mash-tuns, capable of holding many thousand gallons. Here it is mashed, its residue being sold to the cattle-feeders. The coolers adjoin the brewhouse.

From the coolers the wort descends into what are termed the *fermenting backs*, a series of square vessels of enormous proportions, where it is exposed to the action of the yeast. The alcoholic fermentation here commences with great energy, and continues till the sugar of the sweet wort has been transformed into alcohol. By subsequent distillation from large copper *wash* stills, this alcohol is obtained in a more concentrated state, forming the *singlings* or *low wines* of the distiller.

For the production of whisky, barley is the most abundantly employed of all the cereals, either in the raw or malted state. Malting is a preliminary operation to which the barley is submitted by those who employ malt; but since it is not *solely* used by the distiller, the detailed description of the operations of malting will be considered under the article Beer. To show, however, the influence the malting has on the operations of the distiller, it is necessary to notice one particular change that takes place in the constituents of the grain—namely, the metamorphosis by which first diastase, and afterwards sugar, is produced. Diastase is a peculiar nitrogenous substance, formed during the germination of grain, potatoes, &c. Its proportion in malt does not exceed 0·002 to 0·003 per cent.; but nevertheless it is solely to the presence of this body that malt owes its value as an agent for determining the conversion of starch into grape sugar.

The change of starch into sugar is partly effected in the grain during the time it is permitted to sprout, but principally after it has been infused in water, when the diastase, which has been formed during germination, acts as a ferment on the starch of the grain, and converts the whole of it into glucose (grape sugar, $C_6H_{12}O_6$), which, when fermented, splits up into ethyl alcohol and carbonic acid—

Grape sugar. Ethyl alcohol.

$$C_6H_{12}O_6 = 2CO_2 + 2C_2H_6O.$$

This conversion of the nutritive parts of the grain disintegrates it in such a manner that water readily permeates its entire substance, and takes up the whole of the soluble matter. For this reason malted grain is preferred by many distillers: firstly, because the extract is obtained more perfectly and with greater facility; and secondly, because it is supposed that the yield of spirit is larger than would be produced were the grain unmalted. But as additional labour always involves greater expense, the cost of the malted substance is necessarily higher, besides that the government duty on malt further raises its value. To avoid this expenditure many distillers use a mixture of malted with raw or unmalted grain in various proportions; and though the subsequent extraction and management of the worts from such mixtures present some difficulties, yet they are for the most part overcome by care and foresight, and the yield of spirit is as large as if malt only was taken.

Whether malt is exclusively used or a mixture, the substance must be either ground or crushed, in order to expose an extensive surface to the solvent action of the water in the preparation of the extract. As said before, the malting effects this disintegration to a considerable extent; hence the reason why malt is not required to be in a very minute state of division when subjecting it to the action of solvents; but when mixtures are used, into the composition of which large quantities of raw grain enter, they must be finely ground for the cause just assigned.

Ground or crushed malt always yields a wort that is comparatively clear; mixtures, on the other hand, never give a bright wort, but dense solutions, on account of the large quantities of starch which they contain suspended mechanically in the water.

This behaviour of the malt and mixtures constitutes one of the principal differences between the brewer's and distiller's mode of making the worts; the former must have a clear extract, as the liquid, after being submitted to the slow fermentation, remains to give *body* to his beverage. Such an extract cannot be otherwise obtained than by using malt entirely. With the distiller, it is optional whether he uses malt or mixtures to prepare his worts, since he can run the starchy liquor into the fermenting tun, there to undergo conversion into sugar, and its subsequent alcoholic fermentation.

In other respects the operations of the brewer and of the distiller are closely allied, excepting that the distiller's object is to urge fermentation to its utmost, and finally to separate by distillation the spirit thus formed from the wash, after which the residuary liquor is accounted of little value; whilst the brewer's aim is to prevent the fermentation going beyond a certain point, the alcohol produced being left in conjunction with the wash, and forming beer.

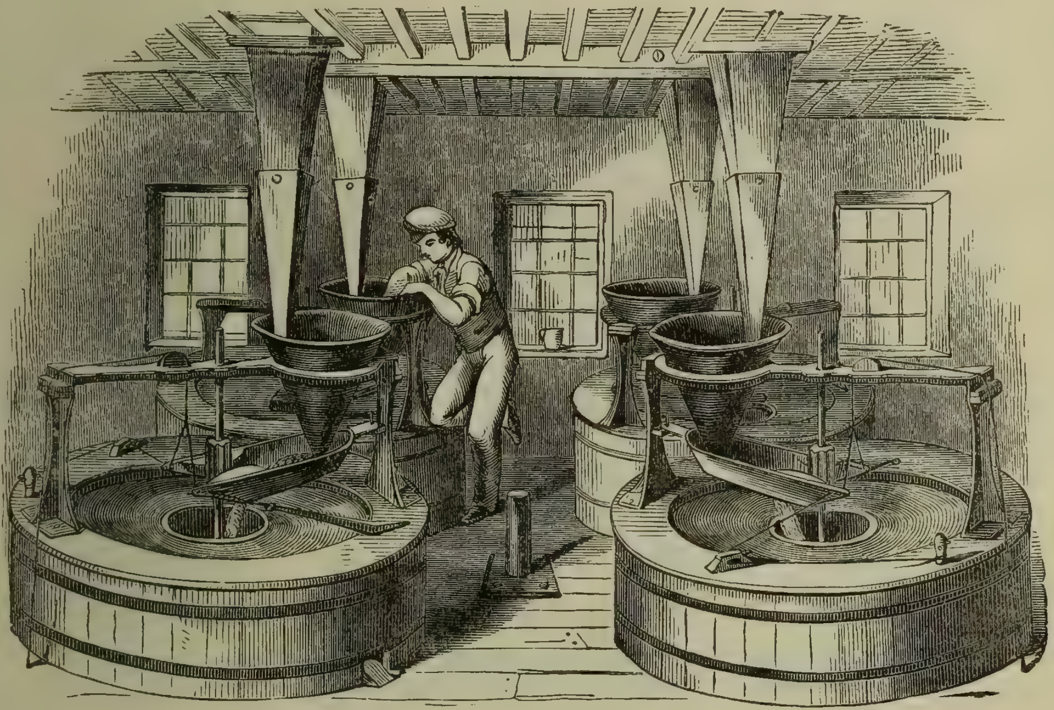
Considerable attention is required of both parties, and especially of the distiller who employs raw grain, in preparing the worts, owing to the tendency of the mixture *to set*, which prevents him from extracting the valuable portions. The main point, however, in the distiller's business, demanding particular care, is the proper management of the fermentative action succeeding the making of the worts, to insure the conversion of the whole of the saccharine matter into alcohol; the acetous fermentation must also be guarded against, and various others difficulties, which, if overlooked, would be extremely detrimental.

The several stages in the manufacture will now be fully treated of under the heads—Grinding, Mashing, Fermenting, and Distilling.

GRINDING.—The granary is a large building of brick or stone, having three spacious stories on which the malt or raw grain is hoarded. One of the granary floors is appropriated to the kiln-dried barley, which lies spread in a stratum 5 feet thick, ready to be conveyed to the mill. When it is to be ground into meal, the grain is taken to a room immediately over the mill-chamber, and discharged through trap-doors into cloth sleeves, which conduct it to the hoppers leading into the mill-room. Fig. 3 shows the nature of the operations. These stones grind all the raw grain; while the malt is passed through a crushing-mill, consisting of two rollers placed nearly in contact. In the lower room is the mechanism by which the millstones are rotated in the room above, and also the pipes for conducting the meal from the grinders into sacks. The meal, as it issues from these pipes, is heated to about 100° Fahr. (37°·8 C.) by the mechanical friction of the stones.

MASHING.—The mash tun is made of cast-iron plates, firmly bolted together and circular in shape. Fig. 4 represents the mash tun at a large Scotch distillery: *a a* is the mash tun, 28 feet in diameter and 8 feet deep. It is furnished with a false bottom, pierced with holes like a strainer. From the middle of the tun rises a vertical shaft, *m*, set in motion by machinery, and thus revolving the mechanism, *d c c*. This apparatus, by rotating horizontally and vertically, effectually agitates the whole of the liquor in the tun: *d* is a rod extending from the pillar, *m*, to the edge of the tun, round which its outer extremity is carried on a toothed wheel, gearing into the teeth round the tun; it is driven by the bevel wheels, *n*. Connected with this rod, *d*, are two parallel rods, *c c*, which it carries round with it: to these rods are fixed bent cross bars, which also revolve in consequence of the double motion of the rods, *c c*, rotating on their axis at the same time that they turn round the shaft in the centre of the tun. In their mashing and churning action they much resemble the paddles of a steamer. The one rod is exactly over the other; the paddles attached to the lowest pass within 2 inches of the bottom. The platform, *k*, is so arranged that the men may have easy access to the tun; *f* is a door leading to the mill, where the grain is ground into grist; *b b*, two channels or sluices, for conducting the grist from the granary into the mash tun; *e e*, wash-backs, resting on rafters, &c., which project from the wall. The wash-backs are used for containing the weak worts drawn from the last two *sperges*, or mashings of the grist, after the principal extracts have been drawn off; they are pumped up into *e e*, and kept to macerate fresh grist in the next operation. Several large copper vessels, besides the tuns, are in use, for the purpose of heating the water for mashing the grist; they hold several thousand gallons, and are heated by a furnace.

Fig. 3.

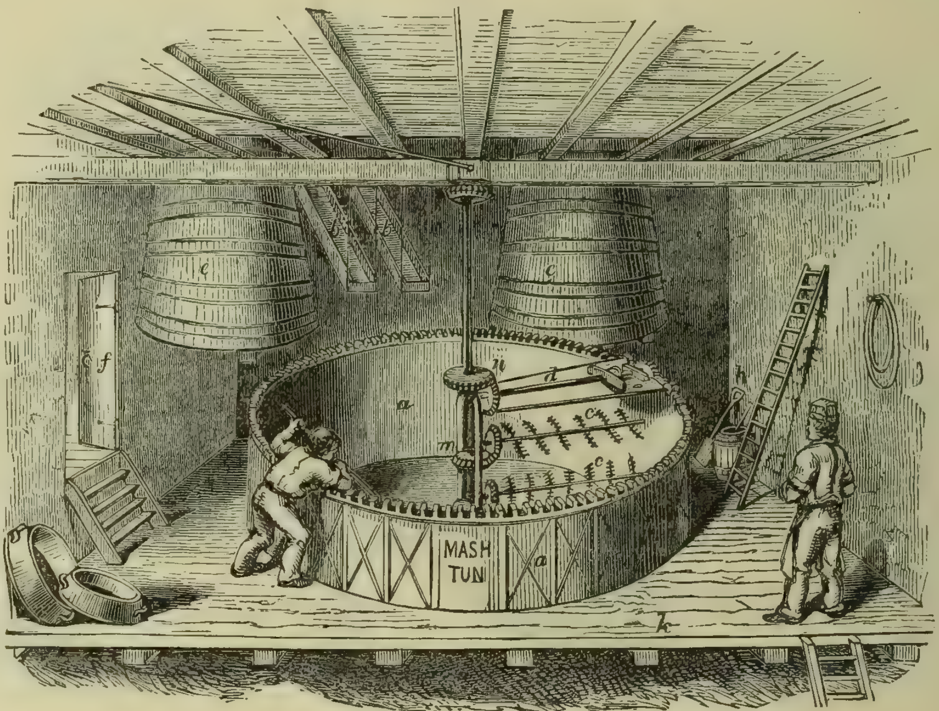


It has already been stated that the grist may be barley meal, oats, or malt, in variable proportions, according to circumstances. Large quantities of oats, on being mixed with the grist, confer a peculiar flavour, which is easily recognized by those who have experience in the taste of spirit. When barley malt and raw barley meal form the grist, 1 part of malt to 2 or 3 parts of the raw ground grain are considered the best proportions, though 1 part of malt to 5, 6, 8, 9, or even 15 parts of the raw grain are often used. When oats are employed the best proportion is 3 parts of barley malt to 1 of oats; but satisfactory results are obtained when malt and oats are used in the ratio of 2 of the former to 1 of the latter. If the proportion of raw grain be large when compared with that of the malt, it is a general custom to add a quantity of chaff, in order that, when the mashing water has extracted the saccharine and starchy portions, it may be more easily filtered or drawn off.

The quantity of malt and grain used at each mashing depends on the size of the distillery; hence no fixed rule can be laid down. In the distilleries in Dublin the quantity of grist at each brewing varies with circumstances, from 800 bushels, the lowest, to 2000 bushels, the largest quantity. In nearly all cases it is composed of seven-eight parts of raw or unmalted, and one-eight part of malted grain.

Previous to introducing the malt a quantity of water, at a temperature between 140° and 150° Fahr. (60° to 65°·5 C.), is run into the mash tun, and the ground malt and meal are then added. Workmen, with stout wooden spatulas or oars, keep the mixture in brisk agitation until the grist is thoroughly moistened, and neither clots nor lumps remain. In the larger establishments this part of the operation is effected by machinery. The perforated false bottom allows the wort to percolate into the space between it and the true bottom of the tun, from which it is drawn off more easily into the underbacks—large vessels placed beneath the mash tun, wherein the worts are collected till pumped into the cooling-backs. Distillers and brewers are more variable in their mode of working than any class of manufacturers who carry on business extensively. In no one operation do they seemingly follow a common rule, each having some favourite plan of his own of a supposed greater merit than others; hence the difficulty of giving a true and comprehensive detail of these branches. This assertion has been partly demonstrated already when speaking of the grist; and in the present operation—the mashing—it becomes still more manifest.

Fig. 4.



In France the mode of saccharification is to run in 6 to 7 hectolitres of water at the temperature of 50° C., then to add the 400 or 450 kilos. of malt, which gradually suck up the water. Lastly, by means of a pipe between the two bottoms, 36 hectolitres of water are run in at the temperature of 75° to 80° C.

During the operation of mashing the diastase dissolves in the tepid water and immediately reacts upon the starch of the malt (which has been modified and rendered more easy of conversion by germination), which it by degrees transforms into dextrine and glucose. An excess of diastase remains in the mixture, which is available for acting on raw grain, which may be now added if the temperature of the mash remains sufficiently high to determine the conversion of its amylaceous matters into starch.

In France and Belgium rice flour is added little by little at this part of the process, and subsequently beneath the false bottom a sufficient quantity of water, heated to 80° C., to raise the temperature of the whole mash to 70° C. Under these circumstances the rice starch is by degrees converted into sugar by the malt diastase. The whole is covered over and left for two or three hours, after which, to complete the saccharification, 40 hectolitres of water are run in beneath the false bottom. In an hour and half the operation is esteemed finished.

The brewer does not desire complete saccharification, some dextrine being necessary to him. The distiller, on the other hand, requires nothing but glucose in his mash.

The whole of the saccharine and fermentable matters of the grist introduced into the mash tun is generally extracted in three, always in four mashings at most; but the manner of doing so is different, according to the notions of the manager. In some cases the first, second, and third mashings are evaporated till the mixture acquires a spec. grav. of about 1·05, when it is thought to be ready for the fermenting tun, the fourth wash being reserved for extracting fresh quantities of grist. Other distillers employ such quantities of water in the first and second extracts as will allow the wort to be of a strength fit for fermenting; the third and fourth washings are then concentrated by evaporation to the proper density, and added to the first and second; or else are made of the proper strength by running them n fresh quantities of ground malt and grain. Others, again, manage the quantity of water in such a manner that the product of the first extract has the density necessary for fermentation, the remaining three washings being rendered stronger either by evaporation or mashing with fresh portions of malt or grist. In the latter case the quantity of water is larger in the first mashing.

In Macfarlane & Co.'s distillery at Glasgow 260 cwts. of grist, including a sixth or a fourth of malt, are taken for an ordinary mash. These are put into the mash tun, and about 788 barrels of water, nearly 28,368 gallons, are poured upon them at two stages of the operation. The first water is employed at 140° Fahr. (60° C.), the second water at 175° to 180° Fahr. (79° to 82° C.); the whole contents of the tun being brought to 150° Fahr (65°·5 C.).

In the Dublin distilleries about seven-eighths of raw grain are employed. The first mash is the only one let into the fermenting tun, the succeeding small worts being kept for the next day's brewing. In preparing the wort about 5 barrels of water are taken to the quarter of grist, but more if small worts are used; to completely exhaust the grist about the same amount of water is required for the last mashing.

The temperature of the water is made to depend on the quantity of malt present; when the malt and raw grain are mixed in the proportion of 1 of malt to 2 of grain, the first mashing may be made at a temperature of 150° to 160° Fahr. (65°·5 to 71° C.); but if the malt and grain be as 1 to 4, 6, or 9, then the water should not exceed 145° Fahr. (62°·5 C.) for the first mashing, in order to prevent the *setting* of the mass. The system pursued in France and Belgium, of adding the raw grain after the mashing of the malt is completed, obviates this difficulty. A longer time is likewise required for the first mashing with a large quantity of raw grain than if it were entirely malt. From one hour and a half to two hours generally suffice for this operation, when the contents of the mash tub are kept in agitation by machinery, and the proper heat of the water has been attended to; though sometimes the time occupied extends to three or more hours.

The time required for the wort to clarify, when it has been properly mashed, is about one to two hours. As the temperature of the solution becomes lower from contact with the grist and from the agitation, it is customary not to add the whole of the water employed in the first mash at once, but to retain from half to a quarter of the liquid, which is added at short intervals towards the middle of the operation. This serves to keep the heat more uniform, and the work is more effectually accomplished.

After the wort has been drawn off into the underback and pumped into the coolers, the second *sperge* is then let in upon the grist remaining in the mash tun, and a similar treatment to the foregoing given to the mash; the time occupied is one hour and a half, and the density of the weak wort is from 15 to 16 lbs. per barrel.

Since the greater part of the saccharine and starchy matters of the grist is extracted in the first infusion, there is but little danger of the mash setting in the second washing, so that the temperature of the water may be as high as 180° Fahr. (82° C.).

After this wort has been let into the under-back, the third and last sperge is made, and in about an hour and a half the wort is drawn off; its density is from 3 to 5 lbs. per barrel. Both these mashings are pumped into wash-backs, and are let down to form the first mashings in the next day's brewing, and thus the work succeeds by *three* sperges or waterings of the grist. In the case quoted, the first is drawn off at the proper density for fermentation, while the remaining two are retained to be further strengthened by additional extractive matter.

On tasting the solution during the infusion of the first wort, a very peculiar difference is observed. At first nothing particularly striking is apparent, but in a very short time the solution begins to acquire a sweetish taste, which becomes more and more perceptible, till the liquor possesses the lusciousness of malt worts. Hence it is evident that the starchy matter of the grist, as it is extracted, is resolved into glucose, or grape sugar. Two causes serve to effect this change: the first and chief agent is the peculiar body *diastase*, which is generated in the malt during the germination of the grain. This body possesses the property of converting much more starchy matter into sugar than is present in the malt. It reacts on the starch of the raw grain, and produces the same action as if the grain itself was malted. The gluten of the grain is capable of producing the same change, but it requires a considerably longer time than the active body in malt. When only 1 part of malted barley is used to 5 of the ground raw grain, the excess of diastase is sufficient to effect the transformation; but when 9 parts of the raw material are used to 1 of malt, the quantity of the active principle in the malt is inadequate to saccharify the whole of the starch, and a portion is consequently left till fresh diastase is formed. This accounts for the longer time and greater trouble involved in preparing the wort for the still when the proportion of raw grain is very large.

When a wort is being made, considerable time elapses before the starch is wholly transformed into sugar, and in the ordinary period allowed by the distillers in the fabrication of the worts, this conversion is never complete, a large portion of starchy matter remaining unaffected. Thus, if it be attempted to make a wort of 200 lbs. of saccharine matter per barrel in the ordinary way, the process fails, in consequence of the starchy matters assuming a jelly-like appearance long before the above strength is attained. In order to obtain the strongest possible wort from raw grain, the diluted extract should be left to repose till the whole of the starch has become soluble and saccharified, when the solution may be drawn off and concentrated by evaporation at a low temperature.

The specific gravity of the first wash is generally about 1·050; the second wash about 1·010 to 1·015; the third, 1·008; and the fourth a spec. grav. very little higher than that of water. The strongest wort procurable from grist, containing over 4 parts of unmalted grist, is obtained by evaporating the first mashing. The strength, even by this treatment, never exceeds 150 lbs. of saccharine matter per barrel, while the wort of malt, treated similarly, may be obtained of 200 lbs. to the barrel.

A wort of 62 lbs. per barrel, which would yield 12 per cent. of spirit of 1 to 10 strength, or 0·90917 spec. grav., is esteemed a good strength. The original Dutch hollands were obtained from a wort considerably weaker.

The whisky made by smugglers in Scotland was long preferred by the inhabitants, and was purchased at a higher price, under the name of Highland whisky. This was partly owing to its being made entirely from malt; but the chief reason was that, from the unfavourable circumstances under which they worked, their wort was necessarily much weaker than that of the legal distillers, and on an average was probably not much stronger than the wort of the Dutch hollands.

When malt alone is used, about 500 bushels, coarsely ground, are introduced in a mash tun of a proper size, and 9000 gallons of water, at a temperature of 160° Fahr. (71° C.), are run in upon it. The whole is kept in brisk agitation by machinery for an hour, then allowed to rest, and after the grains have subsided, about 6000 gallons of wort are drawn off into the coolers. From 4500 to 5000 gallons of water, at 180° Fahr. (82° C.), are then run in upon the residuary grains in the tun, and the mashing continued for about three quarters of an hour; the mixture is then allowed to rest, and the weak worts drawn off. A third treatment of the grain, with the same amount of water, takes up all the soluble matters of the grain; and when this has been drawn off, and the grains have been drained of all the solution, both the second and third mashings are mixed, constituting together 9000 gallons; this mixture is employed next day, at a temperature of 160° Fahr. (71° C.), to mash 500 bushels of fresh malt. When it has become saturated with saccharine matter, it is drawn off into the coolers as before shown, and the residuary grain subjected to the same operation as the grains of the preceding day.

Sometimes rye is used instead of malt: 90 bushels of it are mixed with 190 bushels of raw grain, thus constituting 280 bushels in the whole, for the mashing of which 5200 gallons of water are required. The temperature of this water, as is pointed out in the beginning of the remarks on this part of the subject, should not be so high as when all malt has been used; and as was also stated above, the time allowed for mashing is greater; the subsequent washings are reserved for exhausting fresh portions of grist.

The Cooling.—The worts have a great tendency to form acetic acid, which the distillers oppose by bringing the solution as speedily as possible to that temperature at which the alcoholic fermentation proceeds. Various methods are pursued by different distillers, according to the extent of the factory.

The coolers formerly used were shallow rectangular vessels, into which the first wort was pumped to the depth of 2, 3, 4, or more inches, as soon as it had passed the under-back. They were placed at the upper part of the building, one over the other, and were open on all sides to the winds. Over each cooler were fixed three *flighters*, machines like horizontal windmills, which, when made to revolve, swept a powerful air-current over the worts.

The time of cooling is now much shortened, and the waste of heat lessened, by causing the worts to pass through tubes surrounded by a stream of cold water. By this means, and the use of the proper extent of piping, the wort may be cooled down to the temperature of the surrounding water, or any other intermediate degree that may prove most advantageous. Worts cooled down by this means lose none of their water by evaporation, as they would do if cooled in the flat shallow wooden coolers; and consequently, with the exception of the little alteration in gravity, occasioned by the difference of temperature, the worts remain of the same density that they indicated when drawn from the underback.

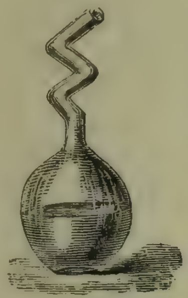
FERMENTATION.—When the clear juice of plants or fruits is exposed to the air for a few hours, at the temperature of 68° Fahr. (20° C.), it becomes turbid, and gives off carbonic acid; in other words, it begins to "work" or ferment, the temperature of the liquid at the same time becoming much higher than that of the air about it. This intestine change continues until the whole of the sugar is decomposed

After the escape of gas has ceased, a multitude of small oval bodies, which do not exceed $\frac{1}{250}$th of an inch in diameter, and which are seen under the microscope to consist of nucleated cells, separates from the liquid. These cells are the ferment or yeast. Their presence is essentially necessary to vinous fermentation. *Bierhefe*, German; *ferment alcoolique*, French; *Torula Cerevisiæ*, botanic fungus.

It has been definitely established that the spores of yeast are universally diffused through the air, and that so soon as they meet with a solution containing the nutriment necessary for their development, yeast cells are produced, and fermentation sets in.

If air be excluded from grape juice or any saccharine solution, no fermentation takes place. Fresh grape juice may be kept for years at the temperature of 68° Fahr. (20° C.), without undergoing any change, provided it never comes in contact with the atmosphere: or if the air has been heated to redness, it may remain in contact with a saccharine liquor for an indefinite time without producing fermentation. But as Pasteur has shown, the motes floating in the air can be collected in cotton or asbestos placed in a tube through which air has been drawn: and a piece of this cotton or asbestos, placed in a sugar solution which has been well boiled, and cooled again, but which contains the mineral and albumenoidal constituents of yeast, develops fermentation. Sugar solutions containing the same yeast constituents, but without this air dust, undergo no alteration, neither do those in which cotton or asbestos alone is introduced. The same liquid remains unaltered if it has been boiled in a glass flask, the neck of which is so bent that dust cannot fall into it, the flask being afterwards left inclosed (Fig. 5.).

Fig. 5.



According to Helmholtz fermentation only takes place when the solution is sufficiently diluted with water. With less than 4 parts water to 1 part sugar it takes place but imperfectly, if at all; partly because the resulting alcohol precipitates the nitrogenous substances, destroys the fermentative power of the yeast, or renders the liquid unfit for its further development. If, on the other hand, the liquid is too dilute, the fermentation is slow, irregular, and readily passes into acetous fermentation. Moreover, it is essential that the yeast be in direct contact with the sugar solutions. A solution of sugar contained in a bladder, suspended within a fermenting liquid, does not ferment, but merely takes up alcohol by diffusion.

Payen states that an increase of yeast takes place in fermentation when the liquid, in addition to sugar, contains a nitrogenous substance. When, on the contrary, yeast is left in contact with a pure solution of sugar, it diminishes both in weight and fermenting power, and finally becomes totally inactive.

Pasteur mixed yeast with a saccharine solution and albumenoidal substances, and exposed the whole to the air in shallow vessels. He found that a quick and active increase of the yeast cells took place, but that only 6 to 8 parts of sugar were decomposed for each 1 part of the newly-formed yeast. When, however, a similar mixture was made and the air excluded, the yeast decomposed about 100 times its weight of sugar, but the yeast grew and multiplied very slowly.

Ménend fermented 100 parts of sugar with 20 parts of beer yeast, and obtained 13·7 pints of insoluble residue, which, when brought in contact with a larger quantity of sugar, diminished to 10 parts. The latter was white, resembled woody fibre, and was no longer capable of exciting fermentation. Hence it appears that the quantity of yeast must bear a definite proportion to that of the sugar; if the sugar is in excess, part of it remains undecomposed, or merely undergoes a very slow after-fermentation, often continuing for years. If, after all the sugar is decomposed, the fermented liquor still contains yeast, or nitrogenous matter not wholly converted into yeast, putrefaction will ensue.

Fermentation is the most important stage through which the materials in the hands of the distiller have to pass, and one which not only demands considerble skill and attention for its proper management, but also requires extensive knowledge, both of the principles of chemistry and of practical results. Indeed, the success of the operation almost entirely depends on the fermentation of the wort; and unless managed with due care and dexterity, a failure will be the consequence.

The proper fermentation of worts sometimes baffles the most skilful, the process being so changeable in its nature. Formerly the Scotch distillers used to add $3\frac{1}{2}$ per cent. of fresh yeast, or 4 to $4\frac{1}{2}$ and sometimes 5 per cent. by measure of stale yeast, to the wort in the fermenting tun. The whole of the yeast was not added at once, but at two, three, four, or more intervals. Usually $1\frac{1}{4}$ to $1\frac{1}{2}$ per cent. of yeast was added the first day, and the remainder on the second and third days; though some distillers introduced the whole of the remaining yeast, after the first addition, on the third day, and, if requisite, a further quantity to complete the fermentation. Fresh yeast, if it could be obtained, was taken at first, and the succeeding quantity put in might be stale yeast; in which case a larger measure was employed than if the ferment were fresh.

The large amount of yeast formerly employed was in consequence of the great density of the worts. Distillers now generally use from 1 to $1\frac{1}{2}$ per cent of fresh yeast, very rarely 2 per cent. Of this about three-fourths per cent. are added when the wort is let into the tun, and the remainder after the second day—sometimes when the attenuation reaches 1·030 or 1·035. The quantity subsequently added may be stale yeast, taking, however, rather more than the usual allowance of the fresh ferment.

This yeast is invariably obtained from the large London porter breweries, the quantity produced in the provincial ones being insufficient. The yeast which is thrown off the porter during its fermentation is the best; though frequently the slimy dregs which remain in the bottom of casks when the clear porter is racked off is sold for yeast. A great deal of the success of the fermentation depends upon the goodness of the yeast, and the quantity used must be regulated by its freshness.

In the course of fermentation the liquid gains about 20 degrees Fahr. (4° C.) above its ordinary temperature. Donovan gives the following as a fair statement of the specific gravity and temperature of the wort of a five days' fermentation, the original specific gravity being 1·050:—

First morning,	temp.,	70°	Fahr.,	sp. gr.	of wort,	1·050
" evening,	"	70°	"	"	"	1·050
Second morning,	"	72°	"	"	"	1·046
" evening,	"	76°	"	"	"	1·032
Third morning,	"	80°	"	"	"	1·022
" evening,	"	84°	"	"	"	1·012
Fourth morning,	"	88°	"	"	"	1·007
" evening,	"	88°	"	"	"	1·005
Fifth morning,	"	88°	"	"	"	1·003
" evening,	"	88°	"	"	"	1·001

The time occupied by the fermentation varies between three and nine days. Difference of season has a great influence on the celerity or slowness of the fermentation. During the first few days the tuns are exposed as much as possible to the atmosphere; after this time they are covered over tightly to exclude the air. Two reasons have been alleged for this arrangement: first, to prevent the escape of the carbonic acid, which, it is supposed, forwards the action; and secondly, if suffered to diffuse itself into the atmosphere, it would carry off portions of the alcohol. For the first supposition some explanation may be offered. It seems that the carbonic acid, when confined, causes the greater attenuation of the liquid. It is known that the carbonic acid from fermenting tuns, when conducted through fresh worts, causes fermentation; though this is not so complete as when yeast is added. Pasteur has proved that this happens in consequence of a portion of the active principle of the ferment being carried over mechanically, and that by this the fermentation is caused; carbonic acid generated from any other source having no such effect. With regard to the second reason, it is scarcely admissible, as the fermentation is nearly terminated before shutting down the tuns.

Distillers never take yeast from the fermenting tuns, but beat it into the liquid, being of opinion that any such abstraction would render the fermentation less complete, and consequently diminish the proportion of spirit.

The best temperature for the wort, when let into the fermenting tuns, is about 70° to 75° Fahr. (21° to 24° C.); during the fermentation the temperature being at the maximum elevation, between 82° and 90° Fahr. (28° to 32° C.). Great care must be exercised to prevent the temperature exceeding 95° Fahr. (35° C.), in order to avoid acetification.

Difference in the time of the fermentation of worts is almost always owing to variation in the quality of the yeast. As the fermentation proceeds the specific gravity of the wort diminishes, in consequence of the decomposition of the saccharine matter into carbonic acid and alcohol, which is expressed by the distillers as *attenuation*, and is the standard by which they judge of the success of the operation. The amount of spirit the wash will yield may be known from the determination of the specific gravity, or degree of attenuation which has taken place.

Two reasons may be offered for the diminished specific gravity after fermentation.

1. The disappearance of the saccharine matter in the fluid. The whole of the sugar, however, is not decomposed, and consequently the specific gravity of the fermented wort would be proportionally greater than the water in its ordinary state, as the quantity of undecomposed matter is more or less.

2. The results of the fermentation are carbonic acid, which escapes, and alcohol, which remains; the alcohol, having a less specific gravity than water, diminishes the density of the latter.

The aim of the distiller is to have the spec. gr. of the wort to correspond with water. When this object is gained, it does not however follow that the whole of the saccharine matter has been decomposed. The weight of a volume of alcohol being much less than that of a corresponding volume of water, it is evident, if both be commingled, that the resulting liquid will have a specific gravity less than the latter; and to make up the strength, so as to equal the density of water, a greater or less amount of saccharine matter is requisite. In other words, a quantity of saccharine matter remains undecomposed, which raises the density considerably higher than that of water at ordinary temperatures. Generally, this quantity of undecomposed sugar increases with the original strength of the worts, as the alcohol generated in the proportionate bulk of those extracts is larger; and with it the decomposition of the saccharine matter is partially arrested, in consequence of the property which alcohol has of preventing eremacausis, or fermentation. This fact is easily proved by adding some alcohol to a portion of the wort in active fermentation, so that the liquid will indicate a specific gravity equal to, or a little below water; the action of the ferment is arrested, and the sugar, necessarily, remains in the liquid intact. If the solution be introduced into a retort, or small common copper still, and about one-third of the liquid drawn off at the temperature of the water-bath, the spent wash in the still run once more into a vessel, and a little yeast added, active decomposition of the sugar sets in, and a corresponding quantity of alcohol and carbonic acid is produced. The case is similar in the fermentation on a large scale: the annexed table shows this very clearly. The density of the nine worts examined ranged about 1·045, and the degrees of attenuation to which they were reduced were as follows:—

1.	Specific gravity	after attenuation,....	1·0012
2.	"	"	1·0045
3.	"	"	1·0018
4.	"	"	1·0000
5.	"	"	1·0012
6.	"	"	1·0045
7.	"	"	1·0047
8.	"	"	1·0007
9.	"	"	1·0007

Upon examining the wash after the termination of the fermenting action, it was found that 4·34 parts of the sugar had been decomposed, and that 1 part remained intact; thus showing that when worts are even purposely diluted, nearly a fifth part of the saccharine matter will escape decomposition; and where worts are much stronger, or more concentrated, of course the loss will be much greater. On the large scale, the attenuation cannot often be carried below 1·0012. Some rare instances may occur, in which the specific gravity may be reduced to 1·000, or even 0·998; but in these instances the worts must be in a proper state of dilution, and the ferment, or yeast, of the first quality.

URE mentions the works of a Scotch distiller, where the wash when let into the tun had a specific gravity of 1·065 to 1·060. The contents of the fermenting tun were 3000 gallons of wash, and the temperature at the time of its introduction 64° to 74° Fahr. (17°·7 to 23°·3 C.). Two gallons per cent. of barm were added, and the liquid agitated. When the attenuation had reached 1·04, another gallon per cent. of barm was added.

When the fermenting tuns are small, the temperature of the worts should be higher than when the reverse is the case. Fermentation is proceeding favourably if the bubbles of carbonic acid mount in rapid succession. Should the fermentation flag, it is almost a hopeless task to restore vigorous action. Some distillers try the addition of *bubs—i.e.*, wort brought into a rapid state of fermentation in a tub by a large portion of yeast; but this plan is seldom successful. The law prohibits the addition of any wort after the expiration of twenty-four hours from the time the fermenting tun is charged, and if it be known that after that time any has been added, the distiller incurs a penalty.

With concentrated worts fermentation goes on briskly for a short time, but after the alcohol has accumulated it lags, and no further addition of yeast will revive it. The saccharine matter in such fermented worts possesses a highly disagreeable taste and smell: hence the necessity of having them properly diluted, as well as to avoid waste of saccharine matter. The worts, however, must not be too dilute, as then fermentation ceases sooner, and the diluted alcohol is more apt to run into the acetous fermentation. The attenuation is therefore urged no longer than until the head of yeast falls, the distiller thinking it more advantageous to neglect the matter remaining undecomposed, than to risk loss from the formation of vinegar. To prevent the heavy loss often incurred from this source, immediate distillation of the fermented wort is generally resorted to. Formation of vinegar is detected by the increasing specific gravity of the worts, and the peculiar aroma of acetic acid. It is, however, easily guarded against; since if atmospheric air be excluded from the fermented liquor, no acetic acid is produced. For this purpose the tuns are rendered air-tight by means of a well-fitting cover, through which a large tube passes, and enters the bottom of an open tub placed over the fermenting tun, which in this instance is filled quite full; the rising barm and froth are forced through the pipe into the open tub, and when the fermentation slackens these matters return into the tun. Many distillers use butter to keep the wash from overflowing the tun. In general, the fermenting tuns are conical vessels of much larger capacity than is required to hold the wash when first introduced, and thus serve the double purpose of containing the froth, and preventing the escape of the heat generated during the process.

At present, in the larger distilleries, the fermenting tuns are of iron, with an outer casing of wood. These are found to be much more easily managed than the wooden ones, the iron having a greater conducting power. Should the heat of the wort get too high, cold water is introduced into the space between the envelope and tun; and if it be too cold, it is readily brought to the proper temperature by supplying the jacket with hot water.

Good attenuation is the desideratum, to the attainment of which the distiller's attention is most particularly directed.

In chemistry, by the term alcoholic fermentation is understood that change which sugar undergoes under the influence of the yeast plant, and which produces wine and all other alcoholic drinks. It serves as a type of a number of other analogous phenomena known by the generic term fermentation, but specially designated by the name of the essential product of the particular phenomenon, as the panary, the lactic, the acetic fermentation, &c. The term alcoholic does not include all the phenomena of fermentation in which alcohol is produced, for many kinds have that common character; but the words are used in the sense in which they have been applied by LAVOISIER, GAY LUSSAC, THENARD, and others, viz.: to designate the fermentation of sugar with yeast.

The ordinary proposition, which is to be found at the beginning of this article, that cane sugar ($C_{12}H_{22}O_{11}$) after being modified intogrape sugar ($C_6H_{12}O_6$) by absorption of water, splits up into alcohol and carbonic acid, is according to PASTEUR really only a rough approximation to the truth, although the sum of the weights of the alcohol and carbonic acid represents very nearly the weight of the sugar.

PASTEUR'S researches prove that glycerine and succinic acid are also products of the alcoholic fermentation. Many methods may be used to prove the formation of succinic acid ($C_4H_6O_4$). One of the simplest is to evaporate the fermented liquid after having filtered it to separate the yeast, and then to heat the residue several times with ether, which is afterwards allowed to evaporate spontaneously. In the course of a day or two the sides of the glass are seen to be covered with crystals of succinic acid. At the bottom is a syrupy liquid full of the same crystals: this consists almost entirely of glycerine saturated with succinic acid. This process is not admissible for extracting and estimating succinic acid, but will serve to prove its presence in all fermented liquors, whatever may be their nature and origin.

Glycerine ($C_3H_8O_3$) may be detected in almost the same way, but in place of ether it is better to exhaust the residue with a mixture of alcohol and ether. This mixture dissolves the succinic acid and glycerine, and leaves behind the nitrogenized matter. The ethereal and alcoholic solution is concentrated, saturated with lime, and then evaporated to dryness. The residue is again treated with the mixture of alcohol and ether, which now only dissolves the glycerine, and leaves the succinate of lime.

When it is wished to isolate the succinic acid and glycerine completely, and determine them quantitatively, it is necessary to adopt particular precautions. The principal difficulty in the analysis of a fermented liquid proceeds from the soluble products which the yeast supplies, or which result from its transformations. The nature of these products is always the same, but their proportion varies with the quantities of yeast and sugar employed.

When yeast is mixed with a solution of sugar it gives up to that liquid a part of the soluble principles confined in the interior of its globules. Some saline matters, principally phosphates, and some nitrogenous albumenoid matters are dissolved, and the globules deriving part of their nourishment from these two sorts of substances, live, bud, and multiply. These mutations give rise to modifications of the original products, or to new bodies, some solid and insoluble, others liquid and soluble, which remain in the liquid, and are found therein when the fermentation is finished mixed with the products of the decomposition of the sugar. These general considerations must be borne in mind whilst proceeding to the separation and estimation of the products of the fermentation.

The weight of the yeast employed must first be carefully determined, and an equal weight of the same yeast must be dried at 212° Fahr. (100° C.), and then weighed, so that the amount of dry matter which the yeast contains may be known.

When, on attentively examining the fermenting liquid for some minutes, no bubbles of gas are seen to rise, we may conclude that the fermentation is finished, unless the alcoholic is complicated with the lactic fermentation, in which case the disengagement of gas may cease while a good deal of sugar remains undecomposed. But this is an exceptional case, which only occurs when the yeast employed is stale and contains some of the lactic ferment. In ordinary cases, with a weak solution of sugar, the fermentation is finished in from fifteen days to three weeks, but when an excess of sugar and but little yeast are employed, it may last for months or even years.

The fermented liquor is now filtered through a filter tared with another of the same paper. After drying at 212° Fahr. (100° C.), one weighing will give the weight in the dry state of the yeast deposited in the course of the fermentation. The filtered liquid is then very slowly evaporated to a small bulk, and the evaporation is finished in a vacuum. After twenty-four hours the syrupy residue is treated seven or eight times with a mixture of one pint of alcohol and one and a half pints of ether. Each washing should be filtered, although generally the insoluble matter remains as a plastic mass at the bottom of the capsule. To determine the amount of this insoluble matter it is only necessary to redissolve it in water, evaporate it in a water bath in a weighed capsule, and dry in a stove at 212° Fahr. (100° C.) until the weight is constant.

The flask containing the alcoholic ethereal solution is placed in warm water to drive off the greater part of the ether; the evaporation is then continued at a very gentle heat, and finished as before in vacuo. Pure and perfectly clear lime-water is then added, to exactly neutralize the acid. The evaporation is repeated with the same precautions, and the residue again treated with the mixture of alcohol and ether, to dissolve the glycerine. The succinate of lime remains behind in a crystalline state, contaminated with a small quantity of extractive matter, or lime-salt of an uncrystallizable acid. These impurities may be removed by digesting the succinate of lime for twenty-four hours with alcohol, which dissolves the foreign matters, and leaves the succinate sufficiently pure. It may then be collected on a tared filter, dried and weighed.

The glycerine may be weighed after having evaporated the alcoholic solution at a gentle heat, the evaporation being completed under the air-pump; where, however, it must not remain longer than two or three days, as it continues to lose weight after being deprived of water. In this way all the glycerine is obtained without loss, and it may be regarded as pure when the liquid has been fermented under the influence of a sufficient but not unnecessarily large quantity of yeast. When much more yeast than is necessary has been used, the glycerine will have a sharp bitter taste, because although the yeast itself has been removed by filtration, it contains a very small quantity of acrid matters which are soluble in the mixture of alcohol and ether. Fermentation by itself gives nothing which can render the glycerine impure when extracted as above.

One hundred grammes of sugar candy, fermented with 1·198 grammes of dry yeast, gave after the fermentation:—

Succinic acid,...............	0·673	grammes.
Glycerine,.................	3·640	"
Total,............	4·313	"

That the elements of the glycerine are furnished by the sugar, and that the yeast contributes nothing to it, is proved by a comparison of the weights of the glycerine and yeast in the preceding experiment. But in this case it is not so clear with regard to succinic acid. It is possible, however, by a particular experiment, to obtain an amount of succinic acid larger than the soluble matter of the yeast employed. The succinic acid, therefore, is formed from the sugar as well as the glycerine, and the elements of the yeast take no part in the formation of these products.

DISTILLATION.—The chief object of importance in this stage is the still; and no other article of manufacturing apparatus has undergone so much alteration.

The philosophy of distilling is, however, independent of the construction or form of the still, but rests upon the different degrees of volatility of the bodies subjected to the operation. By attention to this principle, any number of bodies of varied densities may be separated, if suitable means are adopted, the process being termed fractional distillation. The earliest alchemists knew that the more volatile a body, the less heat does it require to convert it into vapour; and *vice versâ*. By transmitting the vapour of two liquids simultaneously through a good condensing medium, the temperature of which is lower than the boiling point of the heavier, but not so low as the point at which the lighter boils, it is evident that the vapour of the heavier liquid will be condensed, while the other retains its gaseous state. This is beautifully illustrated by the subject under consideration. The temperature at which water boils is universally known to be 212° Fahr. (100° C.); alcohol boils at 173°·1 Fahr. (78°·4 C.). If a mixture of these two liquids be introduced into a retort or still, the mixture will boil at an intermediate temperature, proportionate to the quantity of each liquid present; but the alcohol being the lighter is driven over in larger quantity at first, carrying with it some aqueous vapour: as the boiling continues more water is given off, until, at the end of the operation, nothing passes over but steam. When the mixed vapours are conducted through a tube placed in water below 212° Fahr. (100° C.), but not so low as the boiling point of the mixed liquid, the water is condensed, and the alcoholic vapour remains unaffected, till the temperature of the refrigerator is lower than 173°·1 Fahr. (78°·4 C.). This is what happens in distillation with the ordinary apparatus. In the first and second volutions of the worm in the condensing tube, the aqueous portion is more or less condensed, but the spirit retains its acquired elasticity till it traverses the worm to where the temperature is below its boiling point; there it becomes liquid. In the days of the early distillers, when only the common still and worm were in operation, and the whole of the water eliminated with the alcoholic vapours was found in the receiver, it was only by repeated distillations of the first products that a concentrated spirit could be obtained; and this was effected by a great expenditure of time, fuel, and alcohol.

So soon as the attenuation of the wort has reached its lowest point it is run into the still with as little delay as possible. In the old method of working, the wash is distilled in two large retorts or stills, each of from 600 to 1200 gallons capacity, according to the size of the factory. These retorts are provided with a rotatory chain apparatus for preventing the lies from adhering to the bottom of the still, and becoming charred, in which case they would communicate a disagreeable taste to the spirit.

Previous to distillation, about 1 lb. of soap is added to every 100 gallons of the wash. When the charge of wash is 8000 gallons, the distillation is carried on as speedily as possible, and without risk of it "running foul," till about 2400 gallons are drawn off. These constitute the *low wines*, or singlings, and are very weak. The remainder of the spirituous product of the 8000 gallons is received in another vessel for a further distillation. The singlings are redistilled, or *doubled*, in the second still, and the spirit drawn off till it begins to acquire a disagreeable taste and smell. These are technically termed "the faints," and owe their peculiarity to essential oils held in solution. The faints are collected in the faints-back, and mixed with the muddy part of the first distillation, water is added, and the whole redistilled. Very weak singlings are the result, which, upon a second distillation, afford finished spirit.

Some distillers continue the first distillation as long as any alcohol comes over, and then subject the low wines to a second distillation in the spirit still. The first portions are more or less blue or muddy, and consequently are run into the faints-back. As soon as the spirit becomes clear, and devoid of a disagreeable odour, it is run into the spirit-back. The quantity of the spirit obtained in well-regulated distilleries amounts to about three-fourths or even four-fifths of the low wines operated upon; faints are drawn over at the end of the distillation, and are turned into the faints-back, together with the first portions. These faints are mixed, as before stated, with a considerable quantity of water, and distilled, in order to free them from the disagreeable oil eviscerated by the husks of the grain.

A self-regulating bath is, in some distilleries, put in the capital of the still. The common Scotch stills have the capital 15 to 20 feet high, to prevent the wash from boiling over into the worm; it is customary to strike the capital from time to time with a rod, and from the sound emitted, it is inferred whether it be empty, partially filled, or in danger of an overflow; in the latter case the fire is withdrawn or damped by means of a spout near the furnace-door, and which is supplied with water from a cistern in the upper part of the building. When a very pure spirit is required, it is customary to dilute the liquor with water and submit it to a third distillation, in order that the distillate may not have the harsh taste of strong alcoholic liquids. By the use of the improved stills, a liquid 60 per cent. over proof is obtained, even in the first distillation, and at a considerable saving of fuel, time, and labour, while the use of soap, &c., is unnecessary.

The usual yield of proof spirit from malt is between 2 and 2½ gallons per bushel. The largest amount of spirit procured from one quarter of corn is 20 gallons. As a general rule, the lower the heat at which the distillation is carried on, the purer will be the spirit. When an excess of soap has been used, and the distillation urged too rapidly, the distillate often possesses a saponaceous flavour, which is occasioned by its fatty particles being carried over mechanically in the vapour, and dissolved in the alcoholic liquid. The manner in which the soap acts to prevent the charge running foul is as follows:—During fermentation and subsequent transference of the wort into the still, small portions of acetic acid are generated, which decompose part of the soap, setting free the oily compound, which rises to the surface of the liquor, and breaks the bubbles of vapour as they ascend through it from the bottom of the retort; hence the liquid cannot pass over unless the boiling be violently urged.

The average quantity of spirit obtained by the Irish distillers from a barrel of malt, *i.e.*, 12 stones, is $8\frac{1}{2}$ gallons, Irish measure, or 6 gallons 5 pints and $1\frac{1}{2}$ noggins, imperial measure, of 24 per cent. over proof.

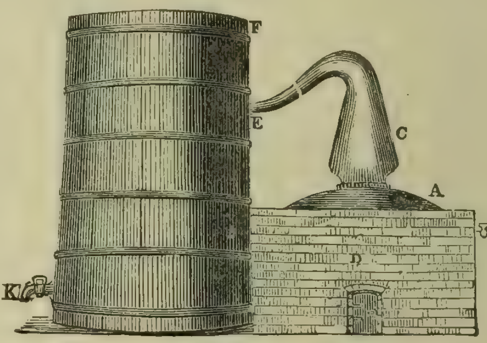
Dr. Ure performed several experiments, at the request of the Board of Excise, for the purpose of deciding a discussion which had taken place in Ireland relative to the extent to which raw grain could be fermented; the most decisive of his results is the following:—3 bushels of mixed grains were taken, consisting of 2 of barley, one-half of oats, and one-half of malt, which, being coarsely ground by a hand-mill, were mashed in a new tun with 24 gallons of water at 155° Fahr. (68°·3 C.). The mash liquor drawn off amounted to 18 gallons, at the density of 1·0465; temperature of 82° Fahr. (27°·7 C.). Being set in a new tun, it began to ferment in the course of twelve hours, and in four days it was attenuated down to spec. grav. 1·012. This yielded, upon distillation, 3·22 gallons of low wines, and after rectification, 3·05 gallons of spirits, the quantity equivalent to the attenuation by the tables being 3·31.

Before the fermented wort goes into the still, a calculation is made by the excise officer on duty of the quantity of wash drawn from the wash-back, which has been pumped into what is called the wash-charger. If the liquor in the charger exceeds the quantity in the back, the distiller has to pay on the higher amount; if it contain less, he must pay according to the wash-back, as being the larger quantity. When all the wash is transferred to the charger, its exit tap is unlocked, and the wash is allowed to be drawn off into the still; the charging and discharging tap of the still being fastened by the officers, so that there can be no transfer of wash except through the pumps. The first distillation from the wash is worked into the low-wine receiver, and the strength and quantity are ascertained by the excise officer and compared with the quantity which the contents of the wash-back had been estimated to produce. This is then pumped from the receiver into the low-wine charger, and after the officer has performed his duty, it is permitted to be drawn off into the low-wine still, which is a distillation of the second extraction; the low-wine still then works into another cask, called the spirit-receiver; when that distillation is finished, the officer, reattending on regular notice for that purpose, takes the quantity and strength of the spirit therein, and upon the quantity so ascertained he charges the duty. If it happens that the actual quantity of spirit, after the distillation, differs from the hypothetical quantity ascertained by previous calculations, he gives to the government the benefit of the doubt, and levies duty on the higher quantity, whichsoever that may be.

In distilling low wines, one portion of them goes into the spirit, and another into the faints-receiver; these faints are, in the next distillation, united with the low-wines from the succeeding wash-back, and are worked together; the united produce goes partly into the spirit-cask, and partly back into the faints-cask. The operation is thus continued till the backs are emptied. All these backs, chargers, receivers, &c., are secured by locks, the keys of which are kept by the excise officer.

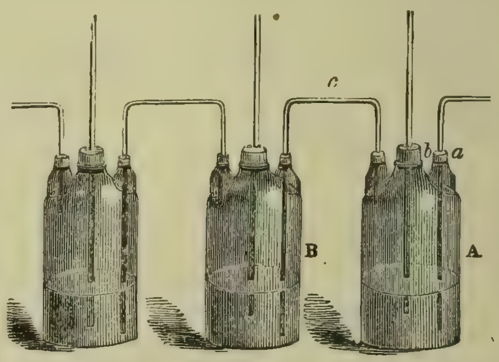
Fig. 6 is a drawing of the common still: A is the body incased in brickwork, D, and directly over the fire: C, the head attached to the condensing-worm, E, placed in the water-tub, F, where the vapour is condensed to a liquid which flows into a receiver at K. The still is of variable dimensions, from 10 to 500 gallons. This form of apparatus was in use for a considerable period.

Fig. 6.



Woulfe, having the principle of Glauber's apparatus in view, was the first to apply the facts already cited, in order to obtain strong spirit, and various other products of distillation. His apparatus bears the name of its inventor to the present day. It is shown in Fig. 7, and consists of a series of bottles, placed in a range. Each of these bottles has three openings or necks; the first bottle was connected with the beak of the still by a pipe or tube, which passes through the neck, *a*, to within an inch or two of the bottom. A safety-tube is introduced through the neck, *b*, and dips into the liquid in the bottle. The bottle, A, communicates with the bottle, B, by means of a pipe or tube, *c*, bent at right angles; in the first it opens a little below the cork, but in the second it passes nearly to

Fig. 7.



the bottom. The second is joined in a similar way to a third and fourth bottle, if required. This apparatus is in constant use in the laboratory, for the purpose of obtaining aqueous solutions of gaseous bodies. The same principle is to be observed in all the various modifications of stills constructed in the beginning of the present century, the most important of which will be described.

In this kingdom, the modifications in the construction of stills have been various. Previous to the year 1788 the old form of still was in general use. From the slowness of the distillation, a week elapsed before a charge was completely worked off, and even then the products were very dilute. At this period the excise duty levied was according to the size of the still, and no further trouble was taken by the officers as to how the worts, &c., were made, except that they visited the distilleries occasionally, to observe if any other stills were in operation, or if larger ones were substituted for those which had been already gauged. About the above period an important revolution took place in the construction of this apparatus by a firm in Leith, by which the distillation was very much expedited. They lessened the height and increased the width of the still, to expose a larger surface to the action of the fire than could be done in the old form; the head of the still was enlarged in proportion to the quantity of vapour generated, and occasionally several outlets or pipes were inserted around the horizontal upper part, to facilitate the escape of the steam and alcoholic vapour into the condensing worm. This still could be charged, distilled off, and be ready for another operation, in the course of a few hours. The inventors preserved to themselves its exclusive use for about twelve months; but such an important discovery could not escape the vigilance of competing neighbours, and hence its use shortly afterwards became general throughout Scotland. The excise, until they became apprised of the fact, were outwitted, the distillers evading the duty which they should have paid for the excess of spirits distilled above the allowance to which the former method of gauging subjected them.

Fig. 8.

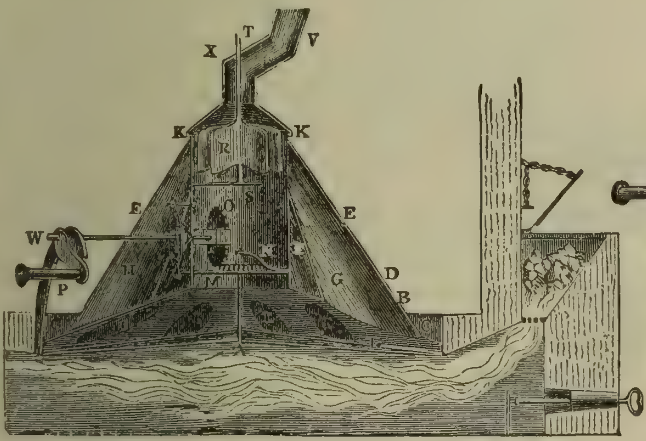
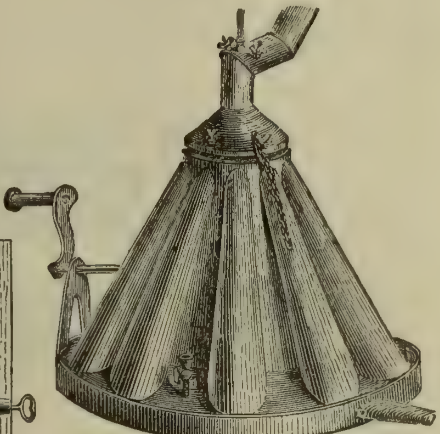


Fig. 9.

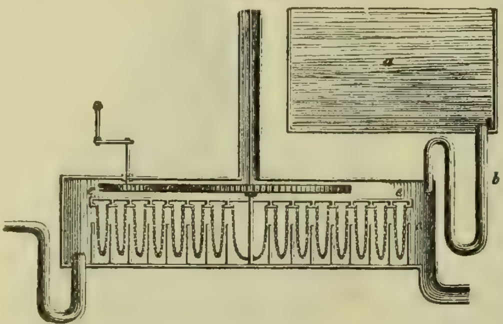


The excise duty, however, was upon this soon altered, and year by year increased; but the distillers, constantly upon the alert, still cheated the overseers appointed by Parliament. At length, in 1799, a parliamentary committee was appointed to investigate this branch of the excise laws. In consequence of their report the distillers were subjected to an excise duty according to the capacity of the still, and on the supposition that it would be worked off and charged every *eight* successive minutes during the distilling season. Even this time was considerably shortened by the distiller; but the amount of fuel consumed, and the consequent wear and tear, left it a matter of doubt whether with any profit. The rapidity of this distillation was carried so far, that in 1815, the last year of the license duty, a still of 80 gallons capacity could be distilled off, emptied, and be ready for a successive operation in three and a half minutes, sometimes in three minutes! A still of 40 gallons could be drawn off in two and a half minutes. An alteration in the excise laws at this time did away with the license duty, and the law became the same as in England, the duty being levied upon the wash and spirits procured therefrom.

For a long time, however, Scotch stills were constructed on the plan of those in use during the period of rapid distillation, namely, by having their bottoms wider than the English stills, in proportion to their size.

The subjoined Figs., 8 and 9, represent a sectional and front view of the Scotch still, at the period when rapid distillation was popular amongst spirit manufacturers. E E is the body of the still, the bottom of which is about 16 feet in diameter, and convex towards the middle; the depth of the still at the centre is about 11 feet, and the sides and bottom meet at an acute angle at the verge. The hollow bottom of the still is connected by solder or rivets with the shoulder, B; C is a rim, which serves to support the still and also to protect it from the fire. D, seen in the front view of the apparatus, is the discharging pipe. In the shoulder of the still are several elliptical openings, from which proceed oblique conical tubes, which enter the cylinder rising from the centre of the boiler; G and H are two of these pipes; I I I I are lower openings; and K K the top openings; F is a section of the central column; L, an agitator within the still, to keep the bottom free from sedimentary—matters a chain agitator was sometimes substituted; M, a vertical axis of the agitator, to which a horizontal toothed wheel, N, is attached; O is another such cogged wheel, but vertical, gearing into the wheel, N, so as to communicate its motion to the latter when required; P, a handle fixed upon the axis of the wheel, O, by which it is turned; W, support of handle and axis; R, a fan to break the froth formed by boiling; its axis rests upon the cross-bar, S. Motion is given to the fan by the vertical axis, T; this axis enters the large pipe that carries off the vapours, through a steam-proof packed box, X; a similar box surrounds the axis of the wheel, O; V is the pipe communicating with the condensing-worm, through which the vapours escape to be condensed.

Fig 10.



The funnel pipe, O, shown in the perspective view, serves to charge the still, and Y is the cover of the central column, which is held in its proper position by chains, as seen at Z.

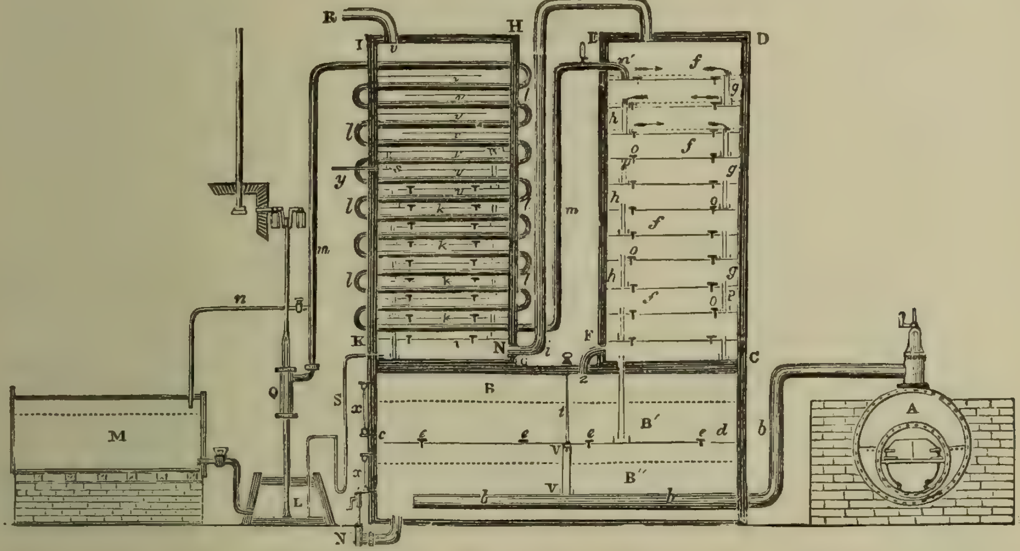
An adaptation of this still, by Sir ANTHONY PERRIER of Cork, is shown in Fig. 10. The liquid to be distilled is made to flow gradually and continuously over the heated surface of the boiler, while it parts with its alcohol. The bottom of the boiler is divided by concentric partitions, sufficiently high to prevent the liquid from boiling over; these partitions have openings from one to another at opposite sides, so as to make the course a sort of labyrinth. *a* is the reservoir of liquor prepared for operation; *b*, a pipe descending from this reservoir, which conducts the liquor into the boiler at *c*, the commencement of the labyrinth, in flowing through which it progressively traverses the whole surface of the bottom, so that the full effect of the fire is exerted upon thin layers of the liquid. This causes the evaporation to proceed with great celerity, and when the liquid reaches the discharge-pipe at the opposite side, it contains no alcohol. The series of chains suspended from the bars, *e e*, which are supported by the central shaft, prevent the deposit of mucus and albuminous matters on the bottom of the still. A toothed wheel and pinion communicate motion to the bars, *e e*, through the shaft, and the chains sweep the compartments between the partitions as they turn round.

The first step towards improving the condensing apparatus was taken by COFFEY of Dublin. In all the preceding stills, though great rapidity of distillation had been attained, yet the great disadvantage remained of having the aqueous and alcoholic portions of the distillate mixed up, so that it was only by repeated distillations that a strong spirit could be obtained. COFFEY inserted two pipes in the first and second rounds of the condensing worm, and led them back to the body of the still. By this simple contrivance a great part of the water was removed from the mixed alcohol and aqueous vapours by being condensed in the first convolutions, and returned to the still instead of flowing into the receiver with the spirit.

Subsequently COFFEY patented another still, which gives in continuous distillation the strongest spirit that can be obtained on the large scale. Fig. 11 is a section of this still. The body of the apparatus consists of an oblong vessel, B, and two columns erected thereon, C D E F and G H I K. The first of these columns is called the analyzer, the second the rectifier. The whole is made of wood, lined with copper, and the wood being 5 or 6 inches thick, little or no heat is lost by radiation. The oblong vessel has a copper plate or diaphragm, *c d*, across the middle of it, which divides it into two chambers, B′ B″. This diaphragm is perforated with a great number of small holes, for the passage of the vapour upwards, and it is also furnished with several valves, which open upwards, as shown at *e e e e*, whenever the vapour is in too great quantity to find a free passage through the perforations. A pipe, V V, fitted with a valve, which can be opened or shut at pleasure by means of a rod, *t*, passing through a stuffing-box on the top of the vessel, descends from this diaphragm nearly to the bottom of the lower chamber, into a pan forming a steam trap. Glass tubes, at *x x*, show at all times the level of the liquor in the chambers, B′ B″. The column, C D E F, which is called the analyzer, consists of twelve chambers, *f f f f*, formed by the interposition of eleven copper diaphragms, marked *g h*, which are perforated with very numerous holes, and furnished with valves, *o o o o*, opening upwards. To each of them is also attached a dropping pipe, *p*, by which the liquor flows from plate to plate; the upper end of each pipe projects an inch or two above the plate in which it is inserted, so that at all times, during the distillation, a stratum of wash of that depth remains upon each diaphragm. The lower end of each pipe dips into a shallow pan on the diaphragm beneath, thus forming a steam trap, by which the escape of vapour through the pipe is prevented. The pipes are inserted at alternate ends of the diaphragms, as shown in the figure.

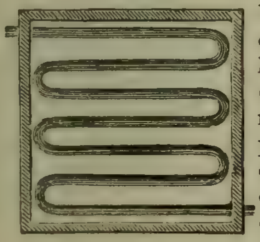
The column, G H I K, is divided into chambers by interposed copper plates, in a similar manner to that just described. There are fifteen chambers in this column, the lower ten, *k k k*, &c., constitute the rectifier, and its diaphragms are perforated and furnished with valves and dropping pipes, precisely similar to those of the analyzer. The upper five form the finished spirit condenser, and are separated from the other ten by a copper diaphragm, without perforations, but having a large opening at W, for the passage of alcoholic vapour, and a dropping pipe at *s*. Round the opening, W, is a neck, rising an inch or so above the surface of the diaphragm, which prevents the return of any finished spirit by that opening. Under the dropping pipe, *s*, is a pan much deeper than those of the other dropping pipes, and from this pan a branch pipe, *y*, passes out of the apparatus and carries the condensed, but still very hot spirits, to a worm, or other refrigerator, wherein they are cooled. The chambers, *v v v v v*, of this spirit condenser are formed of plain unperforated diaphragms of copper, with alternate openings at the ends, large enough both for the passage of the vapour upwards and of the condensed spirit downwards; the use of these diaphragms being merely to cause the vapour to pass along the pipe, *m m*, in a zig-zag direction, and to be thus more perfectly exposed to its condensing surface.

Fig. 11.



In every chamber, both of the finished spirit condenser and of the rectifier, is a set of zig-zag pipes, placed as shown in the plan, Fig. 12. Each set of these pipes is connected with the others by the bends, *l l l l*, thus forming one continued pipe, *m m*, leading from the wash pump, Q, to the bottom of the rectifier, whence it finally passes out, and rising up, enters the top chamber of the analyzer, where it discharges itself at *n'*. M is the wash charger; L, a smaller wash vessel connected with it and with the wash pump. This vessel is called the wash reservoir; its use is to retain a sufficient reserve of wash, to prevent the apparatus being idle during the delay, which the excise regulations render unavoidable, between the emptying of the wash charger and the refilling it from a new back.

Fig. 12.



The pump, Q, is worked continuously during the distillation, so as to supply the apparatus with a regular stream of wash. It is so constructed as to be capable of furnishing somewhat more than is necessary, and there is a pipe, *n*, with stopcock, by which part of what is pumped up may be allowed to run back, and the supply sent into the apparatus regulated.

The steam from the boiler A is conveyed into the bottom of the spent wash receiver by the pipe, *b b*, which, after entering the receiver, branches into a number of small pipes, perforated with holes. The steam is thus dispersed through every part of the wash in which the pipes are immersed. These perforated pipes are not shown in the drawing.

When commencing an operation the wash pump is set in motion to charge all the zig-zag pipes, *m m m*, until the wash passes over into the analyzers at *n'*. The pump is then stopped, and the steam let into the bottom of the apparatus by the pipe, *b b*. The steam passes up through the chambers, B'' B', and by the pipe, *z*, into the analyzers, whence it descends, through *i*, to the bottom of the rectifier at N. It then rises through the chambers, *k k*, enveloping the zig-zag pipes, and rapidly heating the wash contained in them. When the attendant perceives, by feeling the bends, *l l l*, that the wash has been heated in several layers of these pipes, perhaps eight or ten layers (the number is not of much moment), the again sets the pump to work, and the wash, now nearly boiling hot, and always in rapid motion, flows from the pipe *m* at *n′*, and passes down from chamber to chamber through the dropping pipes, in the direction shown by the arrows in a few of the upper chambers. It may be here observed that no portion of the wash passes through the small holes perforated in the diaphragms which separate the chambers. These holes are regulated, both in number and size, so as not to be more than sufficient to afford a passage for the vapours upwards, when under some pressure. The holes, therefore, afford no outlet for the liquor, which can only find its way down in the zig-zag course indicated by the arrows. It is therefore obvious that the wash, as it passes down, is spread into as many strata as there are diaphragms, and is thus exposed to the most searching action of the steam constantly blowing up through it. As it falls from chamber to chamber its alcohol is volatilized by the steam passing upwards; and by the time the wash has reached the large chamber, B, no trace of the spirit remains. The wash, as it descends from the analyzer, accumulates in the large chamber, B′. When this vessel is nearly filled, which can be perceived by inspection of the glass tube, the attendant opens the valve of the pipe, V, and discharges the contents of B′ into the lower compartment: then shutting the valve, the wash from the analyzer again accumulates in B′, and when it is nearly full, the contents of the lower chamber are discharged from the apparatus altogether, through the cock, N′, and the charge in B′ let down by opening the valve, V, as before; thus the process goes on so long as there is any wash to supply the pump.

When all the wash is gone, water is let into the reservoir, L, and pumped through the pumps, *m m*, to obtain the last portions of alcohol.

It has been already said, that in the ordinary course of the operation the wash is stripped of all its alcohol by the time it has reached the bottom of the analyzer; but as a precautionary measure the chambers, B′ B″, have been superadded, in each of which the spent wash is exposed for about half an hour to the action of the steam blowing through it. There is a small apparatus—not shown in the engraving—by which a portion of the steam in the chamber, B″, is condensed, cooled, and made to flow constantly through a sample jar, in which is a hydrometer, or what is better, two glass bulbs, one of the spec. grav. 1·00, and the other, 0·998. The attendant knows all is right when the lighter of these bulbs floats in the sample; hence the chamber, B, may be emptied without any risk of loss.

The course of the wash being understood, that of the steam requires very little description.

The steam is first blown through the charges of spent wash in the lower chamber of B, thence it passes up through the layers of wash on the eleven diaphragms of the analyzer. In its course it abstracts alcohol from these layers of wash, depositing water in its place. After traversing the whole of the analyzer, the vapour, now containing much alcohol, passes by the pipe, *i*, into the bottom of the rectifier, and as it ascends it envelopes the pipes *m m*, heating the wash, and simultaneously parting with its more watery portion, which is condensed, and falls in a state of ebullition on the several diaphragms of the rectifier. By the time the vapour reaches the passage, W, in the bottom of the finished spirit condenser, it is nearly pure alcohol; and as it is condensed by the wash in the pipes, and falls on the diaphragm, it is conveyed away by the pipe, *y*, to a refrigerator. At the top of the spirit condenser is a large pipe, R, which serves as a vent for the uncondensable gas disengaged in the process, and this pipe also communicates with the refrigerator, so that should alcoholic vapour at any time pass out of the apparatus, no loss is sustained beyond the waste of fuel caused by condensing it by the water of the refrigerator, instead of the wash of the condenser.

The liquor formed on the several diaphragms of the rectifier descends to the bottom in the same manner as the wash falls from chamber to chamber in the analyzer; but as it still contains alcohol, it is conveyed by the pipe, S, to the pump, Q, by which it is raised up with the wash to be again distilled.

A thermometer at *m′* shows the attendant the temperature of the wash as it issues from the pipe, *m m*, into the analyzer, being the only guide he requires for managing the operation: for when the temperature is what it should be, nothing can go wrong in the work. Whenever the thermometer indicates too high a temperature, more wash is let into the apparatus, and *vice versâ*—the quantity being regulated by the tap and the pipe, *n*. Very little nicety is requisite on this point, the fluctuation of a few degrees above or below the proper heat is of little consequence, and it is very seldom found necessary to alter the supply of wash.

The water for supplying the boiler passes through a long coil of pipe immersed in boiling-hot spent wash, by which means it is raised to a high temperature before it reaches the boiler.

The vapour passing through this apparatus is condensed by the wash, and not by water; and no heat is wasted as in the common process.

The continental savans at an early date improved the forms of stills. Poissonier, in the year 1779, proposed a modification of the common still, which would probably have come into general use, had it not been for the better and more ingenious invention of M. Adam, before alluded to. Being an auditor of a course of chemical lectures at Montpellier, during which the merits of Woulfe's apparatus as a condenser was discussed, Adam conceived the idea of constructing a still in which the principles of the apparatus of Glauber and Woulfe should be applied to the condensation of alcoholic vapour. In 1801 he took a ten years' *brevet*, or patent, for his invention, and since that time a complete revolution has been effected in the art of distillation. About the same time Solimani obtained a patent for another form of distillatory apparatus. This gentleman was a physician at Nimes, and formerly lecturer on chemistry and experimental philosophy, and disputed the priority of his invention with Adam; but his patent is dated July, 1801, a few days later than Adam's. Various other modifications of the still and condensing apparatus were shortly after introduced, the most important being that of M. Berard, patented on the 16th of August, 1805.

Fig. 13 is a drawing of Adam's still; B is the body of the still, incased in brickwork, and heated by the furnace, A. The head, I, of the still carries off the alcoholic vapour to a series of egg-shaped copper vessels, H, H, H, the first of which it enters at the top, and terminates at the bottom in a perforated rose, like that of a watering-pot, the holes being about an eighth of an inch in diameter. The first vessel is connected with the second, and the second with the third, by the pipes, K, M, proceeding from the top of each, and terminating at the bottom of the next, in the form of a rose, similar to the pipe, I, the tubes fitting air-tight into them. They are supported on a framework, Q P, the wider end being uppermost. D, D, D are cocks, to show when they are half-full. The last vessel—here the third—is furnished with a bucket, N, soldered to its upper end, and filled with water to condense the vapour; the hot water is drawn off by the stopcock, O. When the still is furnished with four or more oval-shaped vessels, the last two have refrigerators attached to them; if strong spirit be not required, the third may be dispensed with. The pipes, S, R, furnished with stopcocks, connect the second and third vessel with the globe, T, from which the worm in the covered vessel, U, proceeds. V is a large tube, which contains the second worm, being a continuation of the one in the vessel, U, and is filled with cold water by means of a water-pipe, entering at the bottom, though not shown in the figure; and as the water gets warm, it is discharged by the pipe, *c*. Another pipe, *a b*, issues from the head of the vessel, U, and is inserted in the globe, T, a continuation of which, though not shown in the figure, connects this globe with the body of the still, or with either of the egg-shaped vessels, at pleasure; *g g g* connects the vessels U with the body of the still, as also with H, H, H, by means of the branching pipes from their bottoms, which are furnished with stopcocks, *h*, *i*, *k*; the stopcocks, *l*, *l*, *m*, *n*, in the pipe *g g g*, serve to regulate the connection with either of these vessels, as occasion requires it. The pipe and stopcock in the shoulder of the boiler regulate the proper quantity of wine to be introduced; and C, another pipe and stopcock, serves to run off the *vinasse*, or spent wine, from the still, when all the spirit has been eliminated. Another pipe, X X X, connects the three vessels, as well as the capital of the still, with a small worm placed in the vessel, F, the connecting branch pipes being furnished with stopcocks, to open or close a connection with any of the vessels. O O is a funnel pipe, which serves to charge the apparatus with *repasse*, or weak brandy, and is joined with the first, H, and the frame, Q P, by iron stays. The whole of the still and condensing apparatus is constructed of tinned copper, and the pipes connected by solder.

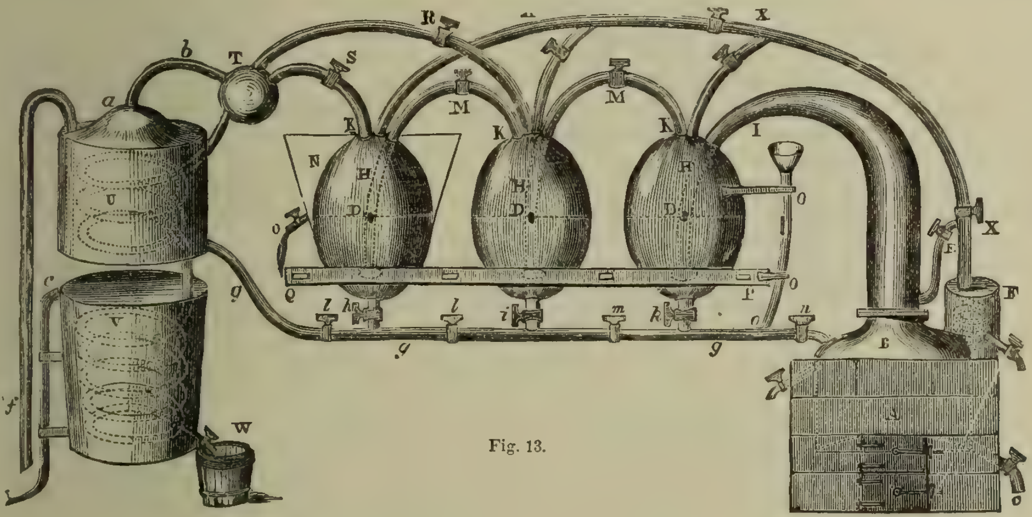


Fig. 13.

Distillation is begun by opening the stopcocks, *l*, *l*, *m*, *n*; also, the pipe in the shoulder of the boiler, and closing the cocks, *h*, *i*, *k*; the vessel, U, is then filled with wine through the supply pipe, *f*, inserted in the cover, by means of a forcing pump, till the wine flows out by the pipe in the shoulder of B; this is then closed, and the cocks, *k*, *i*, *h*, opened in succession, till the wine flows out at D D D, the stopcocks, *n*, *m*, *l*, being closed as the still and first and second vessels are filled in succession. The pumping of the wine is continued until the vessel, U, is nearly filled; the refrigerators, N and V, are then filled with cold water. Everything being thus prepared, all the lower cocks are closed, and the upper stopcocks, M, M, R, S, opened, in order to allow a free passage for the vapour; the fire is then urged on till the liquor in the still begins to boil. The first portion of vapour is richest in spirit, and this passing into the first vessel H, by the capital I, is condensed. The wine in this vessel—which is heated by the vapour rising from the boiler—contains a greater proportion of alcohol, on which account it boils quicker, and cannot reach so high a temperature as the liquid in B. The eliminated vapour from the first H, in consequence of the low temperature at which it is generated, contains less water, and this being condensed in the second, renders the wine which it contains much stronger than that in the first. It consequently boils at a still lower heat. The more aqueous portion of the vapour from the second H, passing off by the connecting pipe, K M, is partly condensed in the third, while the concentrated alcoholic vapour enters the condensing worm in the vessel, U, through the pipe, S, where it is condensed, and flows out into the receiver, W. This receiver is tightly covered to prevent evaporation of the alcohol; and in order that the amount of liquid undergoing condensation may be seen, a glass pipe connects the lower end of the worm and the receiver. As soon as the distilled product, when examined by the hydrometer, shows a diminution of strength, the receiver is changed, and the weaker liquor, or *repasse*, is submitted to a second distillation. The strength of the liquor in the boiler, B, or in any of the condensers, may be ascertained by means of the pipe, X X X, which proceeds from the last, and communicates with the small worm, F, beside the body of the still; from each of the others, as also from the capital, pipes open into it, and as these are each furnished with stopcocks, the vapours from any particular condenser, or the still, may be liquefied in the small worm, F, the other communications being cut off. The spirit as it flows out of the end of this worm is received in a testing glass, and examined by the hydrometer, or by other means. When the liquor in the body of the still is exhausted, the fire is withdrawn, the other communications with the oval-shaped vessels and great worm are cut off, and the cock, C, opened to draw off the *vinasse*, or residue. If it appears that the liquid in any of the condensers is exhausted, it is run off to the body of the still by turning the stopcocks appended to it. The still is next charged by allowing the unexhausted liquor in H, H, H, to flow in through the pipe *g g g*, and the remainder, sufficient to fill the boiler as before, is supplied from the vessel, U. H, H, H may be half filled with brandy, or *repasse*, through the funnel pipe, O O; after which the lower taps are closed, and the upper ones opened as before, and the distillation continued. During the transmission of the alcoholic vapour through the wine vessel, U, the contents become heated, and some spirituous vapour is given off, which may be conducted into the body of the still, or any of the condensers, as deemed desirable, by the pipe *b*, the continuation of which is not expressed in the drawing.

When weak spirit is required, the communication with the third H is cut off by closing the stopcocks, M, S, and opening R, and when an extra strong liquor is required, a fourth condenser is supplied; for the greater the number of condensers, the better and more completely will the rectification be effected. The body of this kind of still is required to be stronger than ordinary, in consequence of the pressure from the Woulffe's bottles, H H H, which, of course, renders the expansive force of the vapour greater.

An elevation of the apparatus of Solimani is represented in Fig. 14, of which Fig. 15 is a section. The distillation is effected by the heat of boiling water. Four stills constitute the set; these are A, A, B, B, in the section, two are placed at each side of the chimney, T. Each pair of stills is connected at the bottom by the pipes, E, E′; the body of each still is about 4 feet square and 18 inches deep, and rests upon stout iron bars, *c c c*, firmly fixed in the walls of the furnace. *d d d′ d′* are the necks of the stills; they measure about 3 feet in breadth, and are long enough to rise above the stone vault, *f*. The heads of the stills are rather low, and their curvature, *g g g′ g′*, rather wide; they are soldered to a large pipe, H H′, which conducts the alcoholic vapour to the copper vessels, K K′, forming a part of the condensing apparatus. Some of the vapour is condensed in these vessels, and forms a liquid layer on the bottom, through which the remaining vapour has to force its way. F F′ are large pipes for carrying off the uncondensed gas into the vessels, I I′, wherein is contained the condensing apparatus, or "dephlegmator." Another small pipe, not shown in the figure, carries off the vapour from I I′ into the condenser, which is immersed in water in the stone cistern, M; and the small pipes, *a a′*, supply the cold water to the vessels I I′ from M.

The stills are charged with wine through the main pipe, P, which branches into them. By turning the stopcocks of this pipe, either pair of stills may be charged with wine, as the pipe, *e*, and the termination of P, reach nearly to the bottom of the body of the stills. The pipe, X, X, supplies the large cistern, M, with cold water.

The condenser in each of the vessels, I I′, is kept cool by a self-acting apparatus, that admits the water from the cistern, M, in the requisite proportion to cool the parallelogram condenser, Fig. 16.

The stills are heated by two boilers, about 10 feet long and 4½ wide, which contain a depth of about 8 to 12 inches of water. *b b b′ b′* show a portion of the flue, which, at the fire, is about 8 inches square, and gradually gets narrower as it approaches the chimney. The length of the flue from the fire to the chimney is about 36 feet, being brought several times back and forth under the boilers, that no heat may be lost. *z z′* are pipes for carrying off the steam into the chimney.

During the time the stills are in the course of being charged, the water in the boilers is raised to the boiling point, and the steam which is generated, circulating around the stills, quickly raises them to the requisite temperature. The alcoholic vapour passes through H H′ into the vessels, K K′; part of it is here condensed, the remainder enters the first condenser through the large pipe, F F′. All the condensed liquid that is formed in this refrigerator flows back through the pipes, F F′, into K K′, where it collects till it rises as high as the bend of the

Fig. 14.

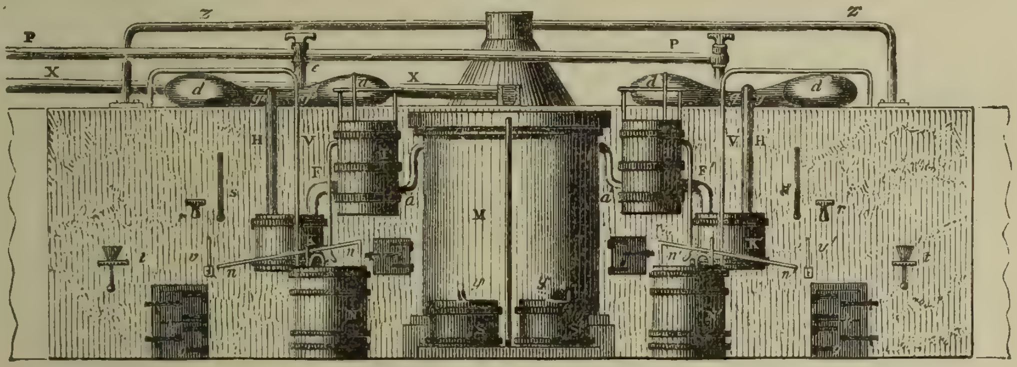
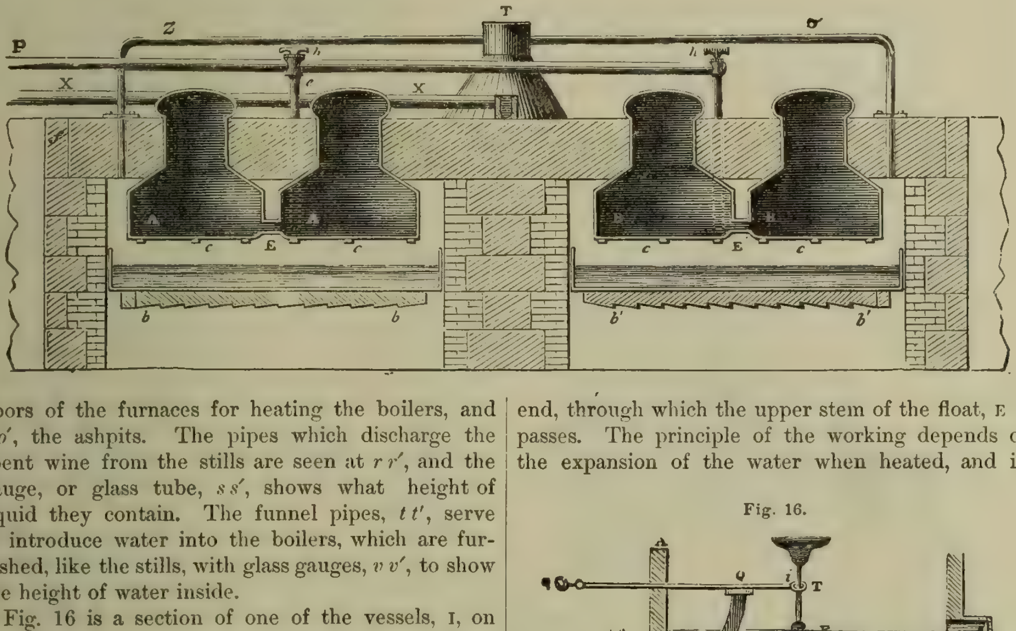


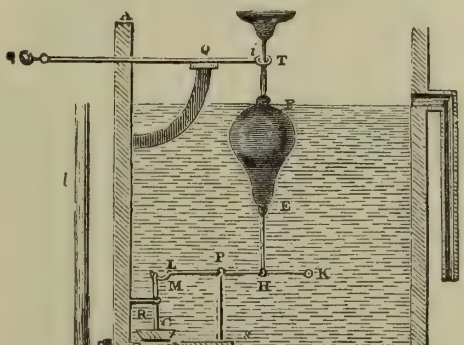
Fig. 15.



attached siphons, when it flows into the large covered tanks, N N′. When N is full, it is pumped into the stills by means of the pumps, *n n n′ n′*, through the pipes, V V′, to undergo a second distillation. *i i′* are doors, by which to enter when any repairs are required by the boilers, &c.; *k k′*, the doors of the furnaces for heating the boilers, and *o o′*, the ashpits. The pipes which discharge the spent wine from the stills are seen at *r r′*, and the gauge, or glass tube, *s s′*, shows what height of liquid they contain. The funnel pipes, *t t′*, serve to introduce water into the boilers, which are furnished, like the stills, with glass gauges, *v v′*, to show the height of water inside.

Fig. 16 is a section of one of the vessels, I, on one side of the condensing apparatus. B is a box fixed on the bottom, having a valve, C, in its upper part, of sufficient weight to resist the force of the stream of water entering the box by the pipe, *l*, from the large condensing trough. E F is a floating ball, bearing on its upper stem, G F, a basin, G, for the reception of weights. The lower stem of the float has a ring at the end, H, through which a sliding rod, K L, passes; this rod has a weight at K, and a hook at L, which passes through the ring in the upper end of the rod, M, attached to the valve, C; K L is supported in the centre by the upright, P; R is a horizontal rod which retains the valve, C, in its proper position, by means of the stem of the latter passing through a ring at the end of R. A sliding rod, S T, supported by the arm, Q, is inserted in the side of the vessel; this rod has a ring, *i*, at its end, through which the upper stem of the float, E F, passes. The principle of the working depends on the expansion of the water when heated, and its proportionate decrease of specific gravity. Sufficient weight is placed on the basin, G, to counterpoise the float at the exact temperature at which it is desirable to have the water. When the water gets hotter

Fig. 16.



than this, the float descends, and pressing on the lever rod, K L, at H, raises the valve, C, upon which the water from the pipe, *l*, enters; when sufficient water has entered to cool down the vessel to the proper degree, the water increases in density, and the float again rises and closes its valve.

When the float does not act with sufficient promptness, the rod, S T, is pushed further into the vessel, which moves the float towards K, increasing the leverage by which it acts on C, and by this means greater force is applied to raise the valve C, in order that the cold water may enter.

The condensing apparatus, or dephlegmator, in the vessels I I′ and M, in Fig. 14, consists of two broad sheets of tinned copper soldered together, so closely as to leave only one-sixth of an inch between them. In the vessels I I′, the dephlegmator forms four inclined planes, and in M M′ it is composed of six. These are the more advantageous on account of the extent of surface which is exposed to the condensing action of the strata of water. Figs. 17 and 18 show the position of these condensers.

Having described the still and condensing apparatus, the manner of working will now be shown. The boilers being replenished with water to the depth of about 8 inches, the fire is urged under them; during the time this is being done, wine runs into the still through P and *e* (Fig. 14), till it reaches the proper height, as indicated by the gauge *s*, when the taps of the supply pipe are turned off. As soon as the water begins to boil, the contents of the still are likewise heated, and the vapour produced is forced to descend by the pipe, H, into the vessel, K, where some of the aqueous portions are condensed. The remaining portion of the vapour traverses the layer of liquid in its passage into the condensing vessel, I. Here the excess of steam is condensed, and flows back into the vessel, K, through the pipe, F; and when the weak and impure spirit collects in this to the height of the bent siphon tube, it is discharged into the tank, N, whence it is again returned to the still by the pump, *n n*. But very little spirit is condensed in I I′, when the apparatus in this vessel for the regulation of the supply of cold water is properly attended to, and the strong alcoholic vapours pass off into the condensing vessel, M, where they are liquefied, and flow out into the receiver, S. When the liquor in the tank, N, appears exhausted, it is no longer returned into the still, but is rejected as useless, and fresh quantities of wine are run in by turning the stopcocks of the pipe, P, and the distillation continued, till the accumulation of tartar and colouring matters renders it necessary to discharge the whole contents, so as to guard against the stills becoming furred.

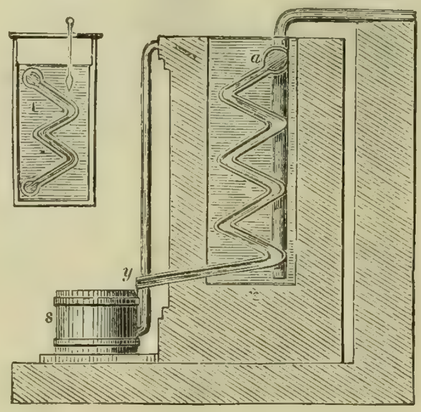


Fig. 17. Fig. 18.

The vinasse is drawn off by turning the taps, *r r′*, and the stills washed by pumping water into them till it comes through clear. This apparatus was found to answer well; but it was not continuous in its operations, and hence much time, labour, and fuel were lost by allowing stills to cool, for the purpose of discharging the spent liquor, recharging, and again raising the temperature sufficiently to effect distillation.

Subsequently to the introduction of ADAM'S and SOLIMANI'S stills, improved ones were announced by BERARD and others. BERARD'S still was not so complex as either of those mentioned, and it was more easily managed; but the loss in fuel was considerably greater, as the operation had to be arrested several times for the purpose of discharging and replenishing the still.

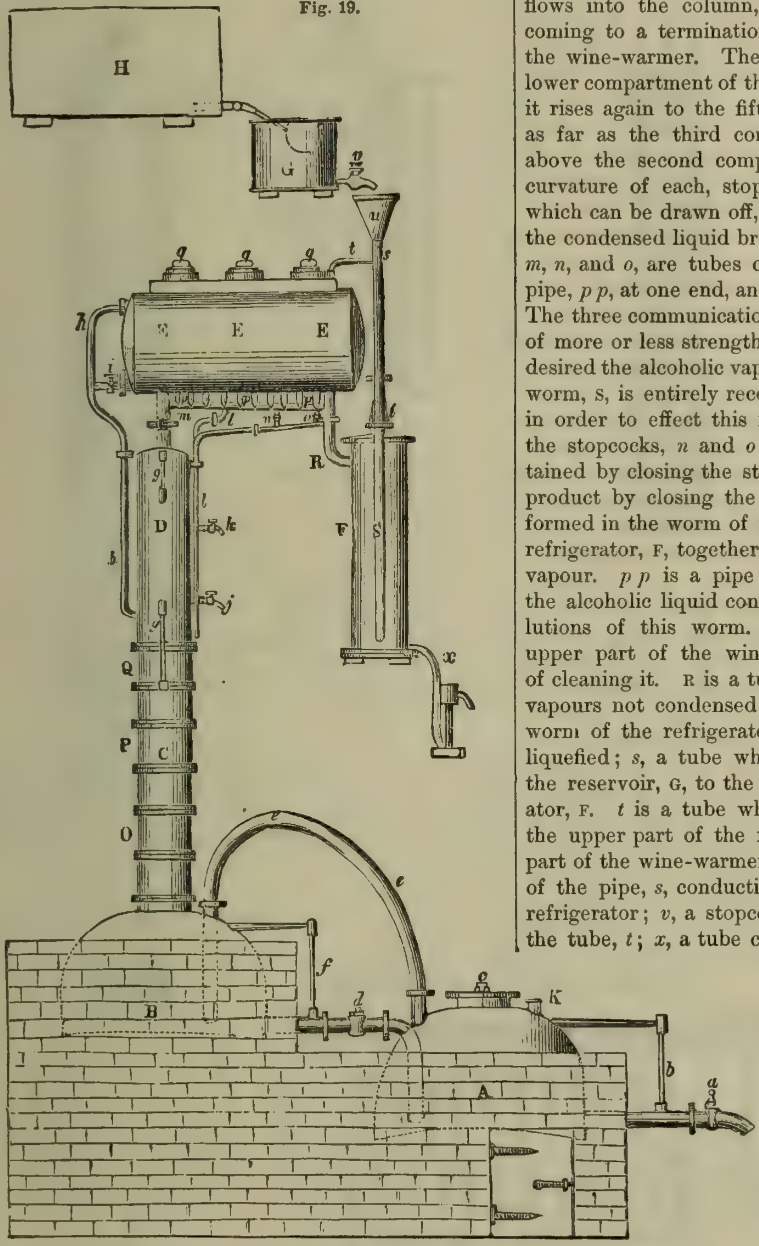
BAGLIONI was the first to conceive the idea of constructing an apparatus by which continuous distillation might be carried out. His attempt, however, was not very successful; but the subject was taken up by CELLIER BLUMENTHAL, who constructed an apparatus which was found to possess, in an eminent degree, all the requirements.

The still constructed by BLUMENTHAL afterwards became the property of DEROSNE, who so very much improved it with respect to continuous distillation, that it in a great measure superseded all the preceding distilling apparatus. The following is an account of DEROSNE'S still on BLUMENTHAL'S principle.

Fig. 19 is a general view of the apparatus. It is composed of seven principal parts:—The boilers, the distilling column, the rectifying column, the condenser and wine-warmer, the refrigerator, the vat where the wine is contained, and the vessel which determines the flow of wine into the apparatus. Of these, A and B are the boilers, encased in masonry or brickwork. The fire is applied under A, and the extra heat is communicated to B by the flue passing under it in its way to the chimney; C is the column of distillation; D the column of rectification; E E the condenser and wine-heating vessel; F the refrigerator; G is a vessel to furnish the wine to the refrigerator. This vessel supplies itself, by means of an automatic tap, from the store-vat, H, where the wine to be distilled is kept. The cock of this part is regulated by a floating ball, which closes it when the liquid rises in G. I is a tube of communication, conducting the alcoholic vapours from the rectifying column, D, to the worm in the condenser, or wine-heating vessel.

The stopcock, *a*, carries off the spent wine from the boiler, E. When the operation is in progress this cock is always open, and the exhausted wine flows off continually; *b* is a gauge-pipe, which indicates the height of the liquid in the boiler, A; *c*, a safety valve or pipe, to show the pressure on the boiler, A; *d*, a stop-cock, which allows the liquid from the boiler, B, to flow into the bottom of the boiler, A; *c c* is a tube that conducts the alcoholic vapours formed in the boiler, A, to the bottom of the boiler, B; the vapour, in passing through B, condenses in part, at the same time heating the liquid; *f* is a gauge to show the level of the liquid in the boiler B; *g*, *g*, level gauges, indicating the height of the liquid in the compartment of the rectifying column, D; *h*, a tube, conducting the wine from the lower part of the condenser, E, to the topmost beveled plates in the interior of the distilling column; *i* is a stopcock, by which all the heated wine in the wine-heating vessel or condenser, E, flows into the column, C, when the distillation is coming to a termination; *l l* are tubes, adjusted to the wine-warmer. The one descends as far as the lower compartment of the rectifying column, whence it rises again to the fifth; the other tube descends as far as the third compartment, and rises again above the second compartment. At the point of curvature of each, stopcocks *j* and *k* are fixed, by which can be drawn off, at will, the small portion of the condensed liquid brought back into the rectifier. *m*, *n*, and *o*, are tubes connected with the inclined pipe, *p p*, at one end, and the pipes, *l*, *l*, at the other. The three communications serve to produce a brandy of more or less strength. If a very strong spirit be desired the alcoholic vapour that is condensed in the worm, S, is entirely reconducted to the rectifier, D; in order to effect this it is only necessary to open the stopcocks, *n* and *o*; a spirit less strong is obtained by closing the stopcock, *o*, and a still weaker product by closing the stopcock, *n*; for the liquid formed in the worm of this cylinder flows off to the refrigerator, F, together with the stronger alcoholic vapour. *p p* is a pipe for receiving the whole of the alcoholic liquid condensed in each of the revolutions of this worm. *q q q* are manholes in the upper part of the wine-warmer, for the purpose of cleaning it. R is a tube conducting the alcoholic vapours not condensed in the wine-warmer to the worm of the refrigerator, F, where they are wholly liquefied; *s*, a tube which supplies the wine from the reservoir, G, to the lower part of the refrigerator, F. *t* is a tube which conducts the wine from the upper part of the refrigerator, F, to the upper part of the wine-warmer, E. *u* is the funnel-opening of the pipe, *s*, conducting the wine from G to the refrigerator; *v*, a stopcock, regulating the flow into the tube, *t*; *x*, a tube conducting the finished spirit from the refrigerator; it is so constructed that an areometer adjusted to it always indicates the strength of the brandy.

Fig. 19.



The interior arrangement of the distilling column is represented in Fig. 20. The surface of the liquid descending through this column is greatly increased by flowing in a thin stratum over the several plates successively, and the alcohol it contains eliminated with great facility by the ascending hot vapour. There are three openings at O P Q (Fig. 19) for cleaning the inside. Ten pair of copper plates are enclosed in this cylinder, and placed in such a zigzag way as to recline downwards alternately, as seen in the section; the liquid, entering at the top, falls over each of the plates in succession, thus making a longer course, and becoming more exposed to the hot vapour.

Fig. 21 is a sectional, and Fig. 22 an exterior view of the rectifying column. Six inverted vessels occupy the interior, and are so arranged that the alcoholic vapour is forced to traverse a thin layer of liquid in each. The condensed liquid returns to the column, C, and the uncondensed vapour passes onwards to the worm in the first condenser by the pipe I.

Fig. 20.

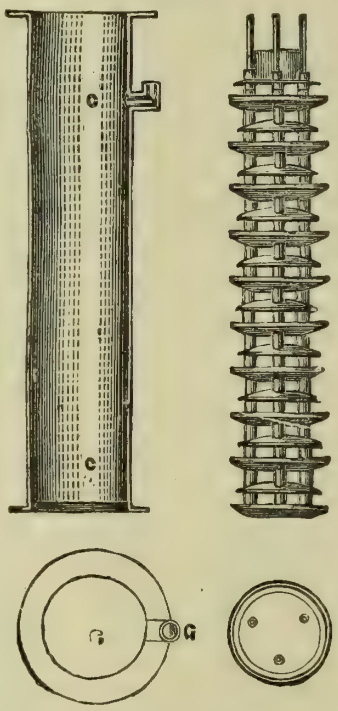


Fig. 21.

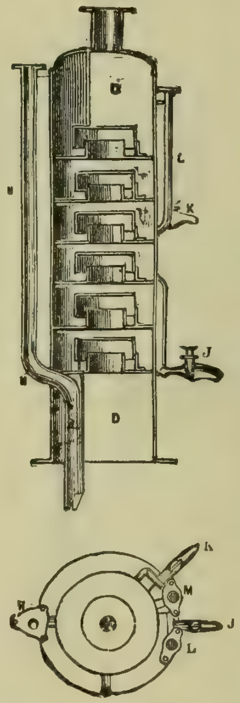
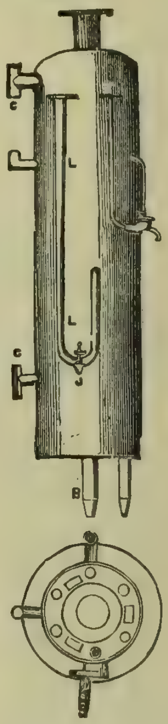


Fig. 22.



In these figures the position of the pipes, L, L, can be better seen; in the front view one is represented descending to the lower and rising again to the third vessel, and the other coming to the third and mounting again to the second; the sectional figure shows the communication of these pipes with the interior of the cylinder. G G are cases for the glass gauges; and the sketches at foot are plans showing the position of the respective tubes, here indicated by dark spots, and the letters, H, M, K, J, and L.

Fig. 23.

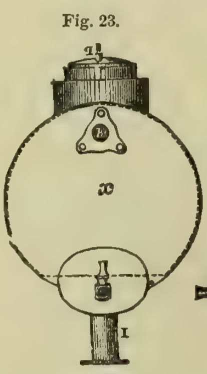


Fig. 24.

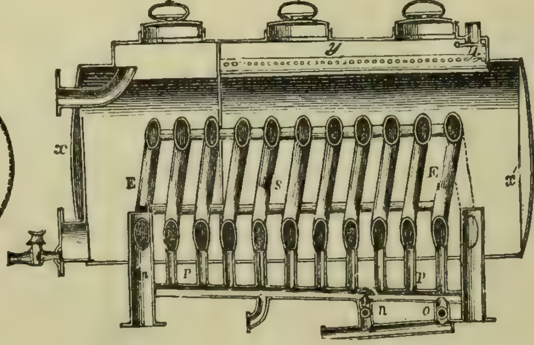
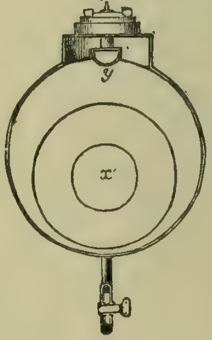


Fig. 25.

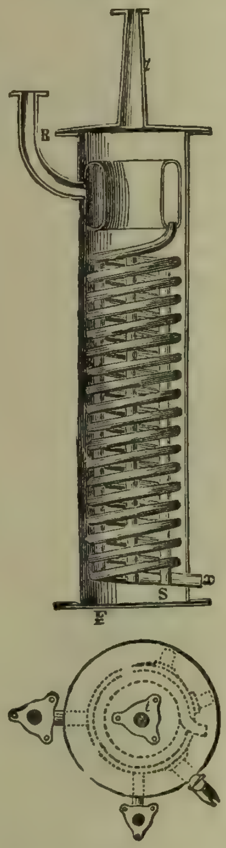


Figs. 23, 24, and 25, are details of the condenser, E, the first being an end view, the second a longitudinal, and the third a transverse section at x', Fig. 24.

At each revolution of the worm, in Fig. 24, it communicates with the canal, $p\,p$, by a short connecting pipe. The wine enters from the pipe, t, shown in the upper part of Fig. 19, and through small holes, as seen at $y\,y$ in Fig. 24, trickles over the worm, which it thereby cools sufficiently to condense most of the water from the vapour passing through it. Fig. 26 shows the arrangement in the refrigerator, S; and the cut appended a view of the top of this column. In these figures the same letters indicate the same parts as in the general view, Fig. 19.

Referring, therefore, to Fig. 19, in connection with the parts shown in detail, when distillation is to commence the boiler, A, is filled with wine through K, to within 2 or 3 inches of the top, as indicated by the gauge, *b*; the fire is lighted, the stopcock, *v*, opened, and the wine allowed to flow into the refrigerator, F, thence into the condenser, E; when this vessel is filled, the liquid flows through the overflow pipe, *h*, into the distilling column, C, and lastly reaches the boiler, B. It is permitted to flow till it rises to within 5 or 6 inches of the top of the gauge-pipe, *f*, when the cock, *v*, is closed. As soon as the liquid in A boils, alcoholic vapour escapes by the pipe, *e*, into the bottom of the boiler, B, where the first condensation takes place, the liquor in this vessel becoming richer in spirit. In a short time the liquor in B, in consequence of heat it derives from the traversing vapour, and of its being rich in alcohol, begins to boil; part of the vapour rising through the distilling column and rectifier is condensed, while the uncondensed portion passes into the condenser through the pipe, I. When the liquid in the condenser becomes so hot that the hand cannot rest in contact with the outer case, the stopcocks, *a*, *d*, and *v*, are opened, and the wine allowed to flow till it reaches the boilers, B and A. As it descends through the distilling column, it is divested of the greater part of its alcohol by the ascending vapour; during its stay in the boiler, B, almost all the remaining quantity is removed, and the very last traces are separated in the first boiler, so that it is completely exhausted as it flows off by the waste stopcock, *a*.

Fig. 26.



In practice, however, it is found that the charge entering into the first boiler from B, if allowed to run off at the full bore of the discharge-cock attached to boiler A, would retain small quantities of alcohol. If the alcoholic liquor remained always in an upper stratum of the liquid in the boiler, then the tap, *d*, might be left open; but in consequence of its constant circulation, no such division can be expected. On this account, therefore, it is absolutely necessary to shut the discharge-cock of boiler A while the liquid is in a state of ebullition, and to slacken the fire while the spent liquor is drawn off from the boiler.

St. Marc, a veterinary surgeon attached to the personal staff of Bonaparte, contrived a still to carry out the principle of uninterrupted distillation. After the battle of Waterloo, St. Marc turned distiller in France, and about the year 1823 he removed to England. Here he and a few others formed a company for the manufacture of brandy from potatoes, and erected large works near London; the project failed, after three years' operation on a very extensive scale.

St. Marc, however, whilst the works were extant, effected many valuable improvements in the form of his still. In 1827 he obtained a patent for the United Kingdom.

This still came into great favour among the principal distillers of London, Bristol, and other towns, though for the distillation of wash it ranks far behind Coffey's. It is said that at the establishment of Messrs. Nicholson at Clerkenwell, one of these stills produced 1000 gallons of gin hourly, the cleansing and flavouring processes proceeding at the same time. It was in great demand, also, for the distillation of rum in the West Indies and several other English colonies, as by its use considerable outlay in fuel, puncheons, freight, and shipping charges were dispensed with.

Figs. 27 and 28 are sectional and front engravings of the still. It consists of seven coppers, placed one above the other, and numbered in the section, 1, 2, 3, 4, 5, 6, 7, of which six contain the wash or liquor to be distilled, and the seventh or upper one water. The coppers, which are held together by flanges and bolts, communicate with each other by the double tubes, A A, through which the vapour ascends, and also by the pipes, B B, by means of which the wash descends from one copper to another in succession, beginning with N 6, into which it is introduced by a pipe and tap, C, from the wash-charger, D. The lowest copper constitutes the body of the still, and receives the heat of the fire, and does not differ from the ordinary boilers; but the second and third coppers each contain four of the double tubes, A, and two of the pipes, B. The fourth, fifth, and sixth coppers have likewise the pipes, B, but have only one double pipe, A, in each, placed under hemispherical domes, E E E, constructed upon, and tightly flanged and bolted to the coppers that have just been mentioned. Six spiral tubes, or vertical worms, F, of which only one appears in the engraving, conduct the vapour from the upper dome through the water in the top division; these communicate with the chamber, G, capped by a small dome and pan, which is kept replenished with cold water, and the portion of vapour remaining uncondensed passes out to the common condensing worm, by the large pipe, H. I shows a pipe and stopcocks for conveying water to the top copper, No. 7, and chamber, G, and any waste water that may be used for scalding or cleaning the backs is carried off by the pipe, K, which is furnished with a branch pipe and stopcock. Water is conducted from the upper copper through the pipe and stopcock, L, to the several lower compartments into which it is introduced by means of the stopcock, M, appended to each; the water is used for bringing down the wash at the close of a back, as well as for cleaning the coppers. The manholes marked N admit of the apparatus being thoroughly cleansed, and facilitate repairs.

The first three coppers—of which the second and third only are intersected with double pipes—distil almost at the same time; the lowest, being that submitted to the action of the fire, operates on the others by the discharge of its vapours, which, ascending by means of the pipes, passes into the wash, and is there condensed, parting with its heat to the latter liquid, which is thereby quickly brought to the boiling point. The uncondensed vapour from the second compartment passes into the third with similar effect. The new vapour, necessarily more alcoholic than the first, ascends into the fourth section, where it is received under a hemispherical dome, which prevents it communicating directly with the cold wash contained in that copper. In this place the greater part of the water is condensed, yielding its latent heat to the wash which surrounds the dome, and bringing it to a higher temperature. The spirituous portion, which passes into the fifth section, experiences the same change as the vapour in the fourth dome, and so on to the uppermost, the alcoholic vapour becoming stronger as it traverses every succeeding dome. The condensed portion in each dome returns through the coppers to the third chamber, and meeting with the ascending hotter vapours, they are partially redistilled in their progress. In the third copper a second distillation commences, giving off anew its alcohol.

Fig. 27.

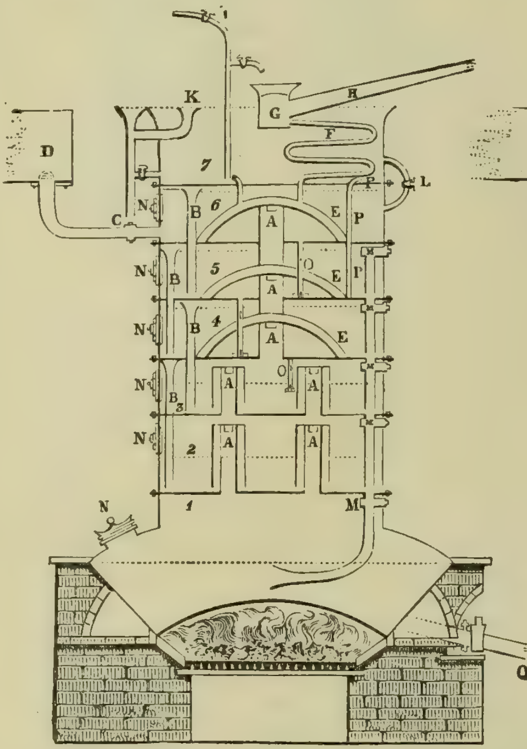
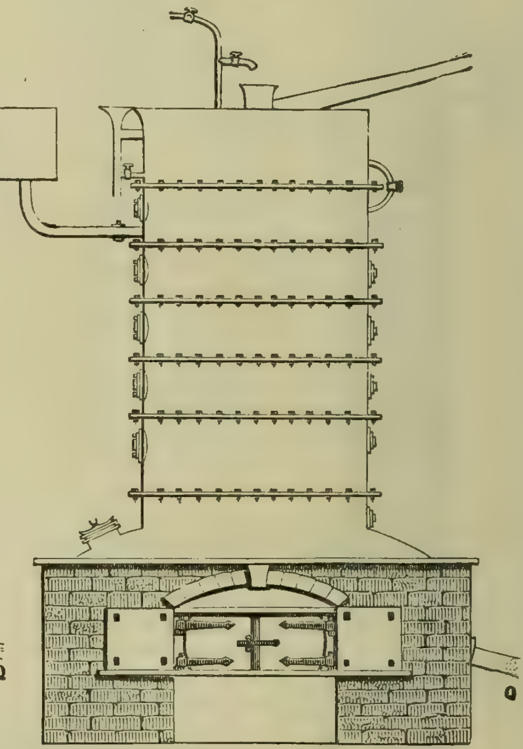


Fig. 28.



A large portion of the spirit being distilled by steam heat, is consequently more pure than that obtained by the ordinary apparatus. Therefore, all the bad flavour that arises from long and violent exposure of the wash to the action of the fire is obviated by this process. One distillation only is effected by the fire; and this is immediately succeeded by two steam distillations, and subsequently by four purifying consecutive processes, which divest the spirit of all impurities, and it comes over, at one operation, of the strength of 35 or 40 per cent. over proof, by Sikes' hydrometer.

A still of seven compartments, such as described, will not produce spirit stronger than 35 or 40 per cent. above proof; but by increasing the number of coppers or sections, a much stronger liquor might be obtained by a single operation.

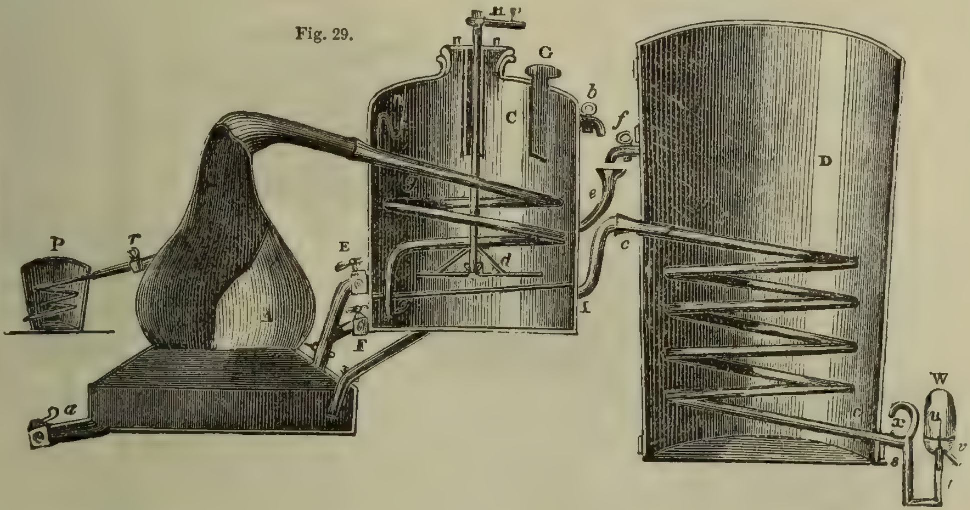
To ascertain the precise time for charging, after the exhaustion of the wash in the lower copper, the proof tap placed in its side is opened, and if the vapour issuing from it will not ignite on the application of a candle, a fresh charge is deemed to be wanting. The discharge of the spent wash from the lowest vessel, the supply from the next copper to replace it, and the opening of the tap in the pipe communicating between the charger and the top of the still to admit more wash, are all the work of about a minute, during which distillation never ceases.

The Germans still use, when working on a small scale, an apparatus for the distillation of the fermented extract of malt, which bears the name of DORN'S still. Fig. 29.

The principal parts are the body of the still, A, the wort-warming vessel, C, and the condenser, D. The still is furnished with a discharging-cock, *a*, and a small pipe with stopcock, *r*, is inserted in the head, which pipe is connected with the end of a small worm in the tub, P. C is an iron or copper vessel, furnished with a double bottom, the one 12 inches above the other. In the upper part of this vessel are contained a few coils of worm, *g g*, the lower end of which passes downwards through the first bottom to within one or two inches of the other. An opening at the top of the wort-warmer receives an agitator, H, which may be turned by the hand; a cross bar, *d*, at the end of this upright rod, stirs up any sediment which may settle on the bottom. The opening, G, serves to charge the vessel with liquor; E and F are communications between both compartments of the vessel, C, and the body of the still, for the purpose of supplying it with the liquor contained in both these parts for distillation; *b* is an overflow pipe and stopcock, by which it is ascertained when C is replenished. A pipe, I, issues from the far end of the lower part of the vessel, C, and is connected with the second worm *c*, *c*, in the large worm-tub, D. Another pipe, *e*, enters the preparer for the purpose of cleaning it with water at the termination of the distillation; the water is run into the boiler of the still, and drawn off at the discharge-cock, *a*. A pipe from an adjacent cistern, or reservoir, supplies the large tub, D, with cold water, and from this tub water is supplied to the pipe, *e*, through the stopcock, *f*.

An apparatus is furnished at the end of the worm, as it issues from the tub, in order that the flow of the liquor may be observed, and its strength noted at the same time. It consists of a tube, bent at right angles, as at *s t*, the upper part of which terminates in a curve, *x*, through which the air of the worm is expelled. The arm, *t*, is terminated in a basin, holding an inverted glass jar, W, in which a hydrometer, *u*, is placed, and floating in the spirit, in order to tell the proper strength. The pipe, *v*, carries off the finished spirit into the tank.

Fig. 29.

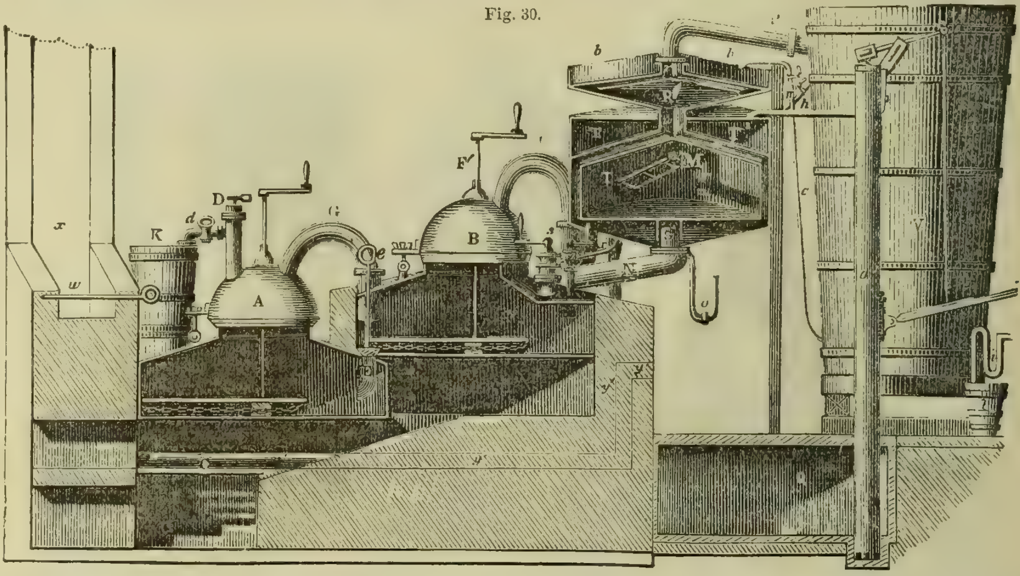


Distillation is begun by filling the wort warmer, C, with liquor, through the pipe, G, till it flows out at the stopcock, *b*, after which the cock, E, is opened till the still is filled to an overflow-pipe, which regulates the amount of liquor to be introduced, but which is not seen in the section. The cock, E, is then shut off; G is closed by a screwed cap or plug, and the furnace lighted under A. As the alcoholic vapour rises, it is partly condensed in the few coils of worm in the vessel, C, the liquid falling down to the bottom compartment; and the liquor in the vessel is heated by the latent heat of the vapour. As the liquor collects in the bottom part of the vessel, the uncondensed vapour gurgles through it, and further deprives it of aqueous vapour; the uncondensed portion then issues through the connecting-pipe, I, to the large worm in the condenser, where it becomes wholly liquefied; the excess of liquid in the lower part being returned to the still by the pipe, F. When the whole of the alcohol has been expelled, the charge in the still is emptied through the discharging-cock, *a*, a fresh supply of the heated liquor from C introduced as before, and a second operation commenced, the fire being slackened while this part of the work is going on. The small condenser attached to the boiler or still is to test whether the charge is wholly exhausted; and the small pipe, *n*, permits the escape of the air in the worm and lower part of the compartment in C.

Since the introduction of a better apparatus, DORN'S is seldom used by the large distillers: it is, however, met with in small establishments, and where brandy is rectified.

The apparatus generally employed throughout Germany for the distillation of fermented worts, &c., is that represented in section in Fig. 30, and known as the Pistorius still. In the figure, A and B are two boilers, connected by the pipe, G. These boilers are each furnished with an agitating chain apparatus, F, F′. C is the fire-grate; after heating the boiler, A, the flue winds under B before entering the chimney, *x*. D is a safety valve attached to the first boiler, which is furnished with a stopcocked pipe, *d*, communicating with a small worm in the condensing tub, K; by this means the distiller is enabled to ascertain when the charge is divested of the whole of its alcohol. The boiler, A, is charged from the contents of the second boiler, B, by means of a connecting-pipe, E, having a valve appended, the handle of which is seen at *e*. A large pipe, L, issues from the head of the boiler, B, and is connected with another pipe, N, of a larger calibre, having another smaller pipe, S, connected with the other end. The alcoholic vapour from the two boilers, A and B, passes through these tubes into the rectifying vessel, M, supplied with a second bottom, from which descends a vertical cylinder over the pipe, S, nearly to the exterior bottom. This passage is made of sheets of copper of nearly the same breadth as the vessel, soldered to an end plate of a few inches in breadth. The remaining parts of the vessel, noted by T T T, are charged with wash for the purpose of heating it before distillation. The spirituous vapour, on passing through this rectifying vessel, loses much water by condensation; but the chief quantity is separated in the double conical space, R, which is surmounted by a vessel of the same form, *b b*, filled with cold water from the large condensing tub. Sometimes the spirit is made to traverse two or three vessels of this kind before passing to the condenser. The pipe, P, conducts the uncondensed alcoholic vapour to the large condensing worm in the tub, V.

Fig. 30.



The liquid formed in the passage *r r r* and R, collects at the bottom of the vessel, M, so that the vapour entering by the pipe, S, has to pass through it. When this quantity becomes too large, the liquor is run into the boiler, B, by the connecting-pipe, *x*′, the flow being controlled by the valve, *y*. *s* is the valve attached to the pipe which conveys the fermented wash from the compartments, T T T, in the vessel, M, to the boiler, B. The pipe, *c*, supplies the conical condensing vessel, *b b*, with cold water, and the pump, *a*, raises the fermented wash from the tank, Q, beneath, and discharges it into the vessel, M, by the pipe, *h*. When the space in the interior of M requires cleaning, water from the condensing tun is run in through the pipe, *m*, by turning the stopcock. The siphon tube, *o*, is for the purpose of expelling the air from the apparatus when the fire is lighted under the boiler, A; it is closed by the stopcock when the alcoholic vapour reaches it.

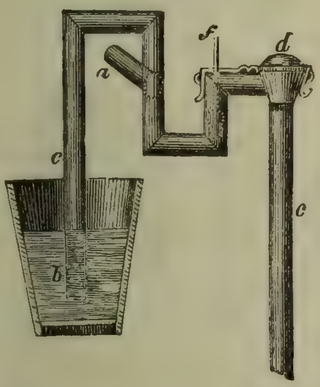
The waste heat from the furnace is made by the pipe, *y*′ *y*′, to warm the water employed in mashing the grain.

The fermented liquor to be distilled is pumped up into compartments, T T T, in the case, M; the valve, *s*, of the pipe connecting the space, T, with the boiler, B, is then opened, and the wash introduced into this boiler, whence it is allowed to flow into the first boiler by opening the valve, *e*, of the connecting pipe, E. This valve is left open till the liquid rises to the proper indication, as shown by a gauge in front, but not seen in the figure; all the taps are then closed. When this is done the fire is lighted. After a short interval, the liquor in A begins to boil, and the vapour passes over into B, whose contents are also raised to ebullition, which takes place at a lower degree in consequence of the quantity of alcohol it receives from it.

The alcoholic vapour from B passes over by L through the pipe, N, into the rectifying spaces, *r r r*, where the excess of the watery vapour is condensed, and falls to the bottom of M. This liquid being the product of the former two distillations is very rich in alcohol; and when it accumulates sufficiently to cover the end of the pipe, S, the hot steam from the boilers bubbling through it disengages a very strong spirit; thus a third distillation is effected. The uncondensed portions rise and pass from the conical-shaped condenser, R, into the large condensing worm in the vessel, V, where they are completely condensed, and flow out at the lower end of the worm into the vessel, or receiver. The three distillations which here take place give a very strong spirituous liquor, and of a very good quality.

At the end of the great worm is a water-tap similar to that shown in Fig. 31. In this diagram, the end of the worm issuing from the great condensing tub is seen at *a*: *c c* is a zig-zag pipe, one end of which is immersed in a bucket of water. In the upright part of the discharging-pipe is an alcoholometer, *f*, by which the strength of the distilled product is ascertained; *d* is a watch-glass covering the funnel-opening in the larger end of the tube, which is used for the purpose of seeing the bulk of the stream of liquid which flows through the worm. By this contrivance the air is prevented entering the worm, and therefore no acetic acid is produced.

Fig. 31.



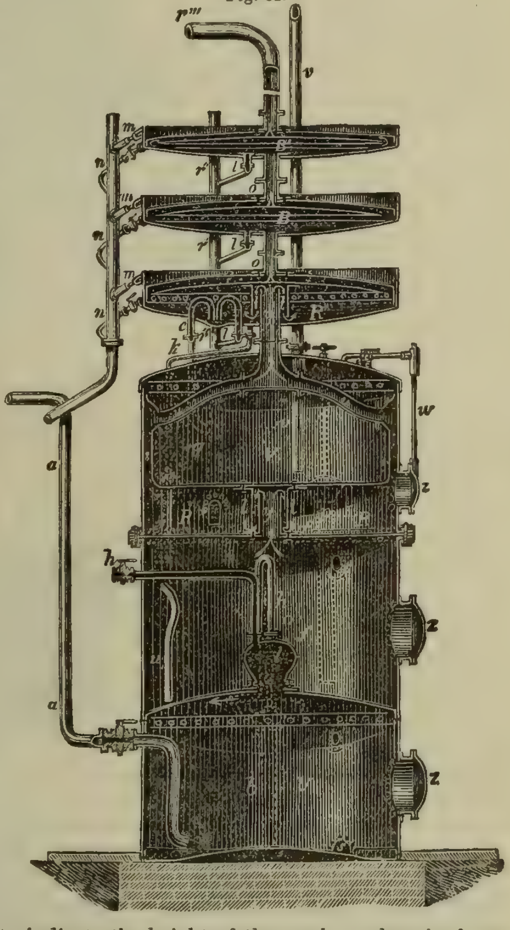
When, on turning the vapour into the small worm in the vessel, K, and collecting the condensed portion, it is found that no more alcohol is contained in the contents of this boiler, the spent liquid is drawn off by the discharge-pipe, a fresh charge admitted from the boiler, B, and this in turn refilled from the compartment in the rectifying vessel, M. During the discharging of the liquid in boiler, A, and its refilling, the fire is slackened, by inserting the damper-plate, *w*, into the flue to cut off the draught.

Fig. 32 is a modification of the PISTORIUS still. Though widely different in form, the principle upon which it is designed is precisely the same. U is the first still, the top of which forms the bottom of the second still, O. The top of U has in the centre a helmet-shaped headpiece, I, out of which springs the pipe *h*, which turns sharp upon itself and descends to the deepest part of the upper still, O, as shown by the dotted lines.

The vapours from the second still pass into the rectifier, R, through the wide tube, *y*, covered with the cap, *l*. From R the vapour passes through the tube, *u*, round the wort-warmer, V, and proceeds through the capped tube, *y′*, *l*, into the basin, R. In this vessel, as in the cap, *l* indicates a second rectification is effected. From R′ the vapours pass through the pipes, *o* and *o*, into two other rectifying vessels, B and B′, and proceed lastly through the pipe, *r‴*, to the condenser.

The wort-warmer, V, is filled with worts from the mash tuns by the pipe, *v*. The glass gauge, *w*, is to indicate the height of the wash: unless its lower opening is very wide it is apt to be blocked up with the malt sediment, and to be fallacious. The wash flows from the preparer, V, through the valve, *p*, and the pipe, *f*, into the second still, O, whence it descends into the first still, U, by the pipe, *b*, shown in the engraving by dotted lines. The exhausted wash is withdrawn through S. The pipe, *h*, on the helmet, I, serves to withdraw a portion of vapour to a worm, to test the progress of the operation.

Fig. 32.



The distillation is performed by means of a current of high-pressure steam introduced into the still through the pipe, *a*. This pipe, and also the pipe *h*, is carried to the bottom of the still, and directs the steam horizontally, so that the wash is kept constantly in motion.

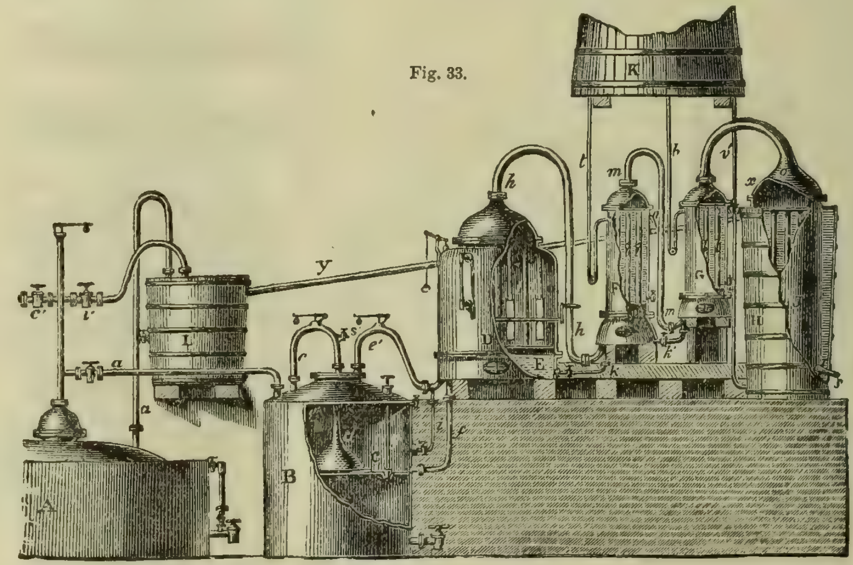
The tube, *u*, shown in the second still, O, leads the liquor from the rectificator, R, back into O, when an outside tap not seen in the engraving is opened. The liquor condensed in the basins, B and B′, flow into the discharge pipe, *r″*, through the pipes, *l l*; thence they are led at pleasure either into the rectifier, R, or the upper rectifier, R′. When it is desired that the upper rectifier should receive them, the tap shown in dotted lines in the engraving is closed, upon which the liquor is forced up the lowest pipe, *l*. The level of the liquid is regulated by the bent pipe, *c*, which also leads into *r″*, and serves to convey the overflow into R, so soon as the liquid covers the bend. This pipe also acts as a siphon, and empties the whole of the liquor into R if a rectifier. The pipe, *k*, also serves to empty the upper rectificator, R′, into the lower R, at any time when desired.

Cold water is supplied to the rectifying basins by the pipes, *n n n*, and the hot water drawn off by the pipes, *m m m*. The manholes for cleaning the apparatus are shown at *z z z*.

A form of steam distilling apparatus, which is in very general use in the south of Germany, was devised by Schwartz, and is represented by Fig. 33.

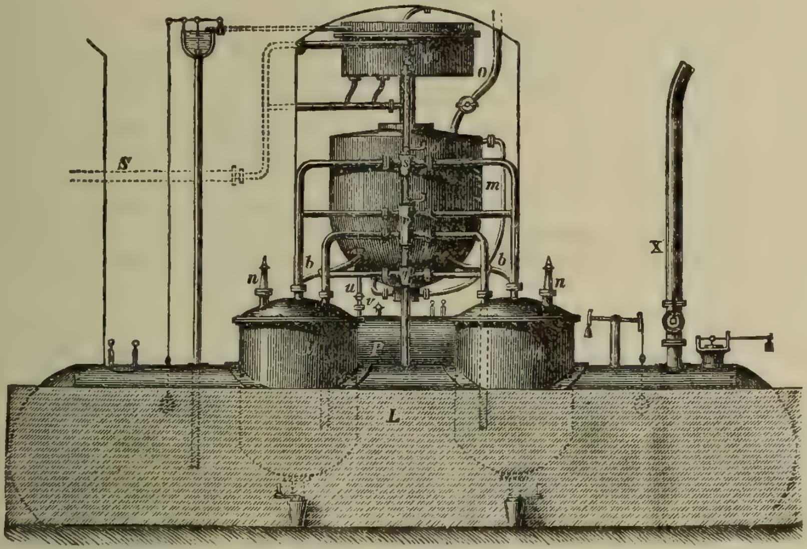
A is a copper steam boiler, supplied with water from the vessel, L, by the pipe, *a′*. B and C are two stills, placed one over the other, and divided by a metal bottom. Steam from the boiler passes through the pipe, *a*, to the bottom of the still, B, heating the wash contained therein to the boiling point, and passing through the pipe, *c*, finds free vent by the bell-shaped enlargement, *d*, into the second still, C, also containing wash. When the wash in the lower still is exhausted it is drawn off through the large tap at the bottom of the vessel, and the still refilled with the heated wash from above by opening the valve, *g*. The alcohol-laden vapour from C then passes through the pipe, *e*, into the lower part of the wort-warmer, D. This part of the apparatus resembles the wort-warmer of the Dorn still, and consists of two vessels separated the one from the other. The lower vessel, E, is a rectifier, and the upper the true wort-warmer. The latter contains eight tubes, *f f*, above and below. The lower ones are screwed into the plate which separates the wort-warmer from the rectifier, the apertures being above the highest level of the liquor. The vapour proceeding from the lower part of the wort-warmer through these tubes becomes dephlegmated by the surrounding cold liquor, and escapes through *h* into the rectifier of the dephlegmator, F, of which counterbalancing pressure is not maintained in the the construction is essentially the same as that of the wort-warmer, D. F contains twelve small tubes, *i i*, surrounded by water. A second rectification here takes place. G is a vessel of similar construction, in which the rectification is carried still further. The vapours from F enter through *m*, and after passing through the liquor enter the pipes, *l l*, from whence they proceed through *c* into the condensing apparatus.

Fig. 33.



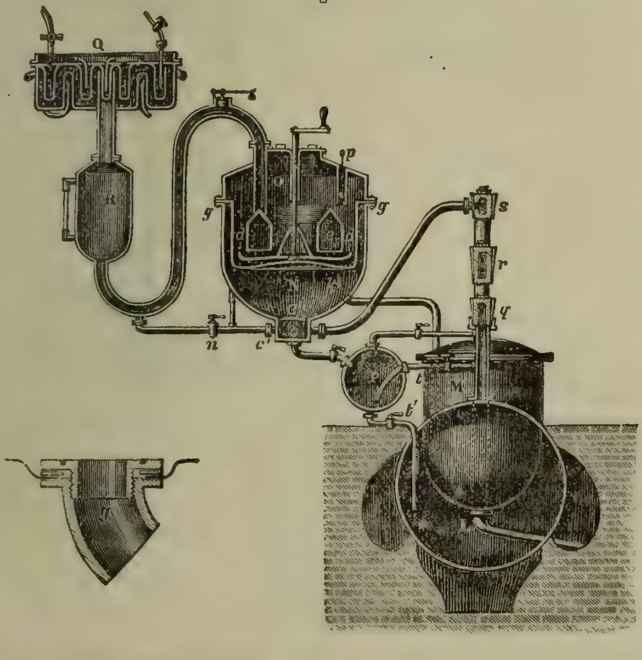
The condenser, H, J, contains twelve perpendicular tubes, opening above and below upon two diaphragms. The alcoholic vapour enters from above, distributes itself through the tubes, when it is condensed, and collects in the vessel under the lower plate, whence the concentrated spirit is withdrawn by the pipe, *r*, *s*. The vessel, J, containing the tubes, is surrounded with cold water, which flows from the reservoir, K, through the tube, *v′*, to the bottom of H, whence it passes into the inner cooler, J, the tubes being thus surrounded with cold water. The heated water flows into the reservoir, L, through the pipe, *y*. The pipes, *b* and *t*, supply the dephlegmators, G and F, with cold water, the warm overflowing through *a* and *w* into *y*.

Fig. 34.



The opening in D, through which the wash is supplied, is not visible in the engraving. The wash, as it is warmed, falls through *f* into the upper still, and thence through *g* into the lower one. The condensed liquor in the rectifier, G, falls through K′ into the rectifier, F; the liquor from F passes through K to the rectifier, E; whilst that from E flows down through *i* into the upper still. The tap, *s*′, allows the air to escape from the apparatus whilst filling it with steam. The tap, *v*, allows of the escape of steam from the hot-water reservoir, L, or by the tap, *c*,′ it is conveyed away to be utilized in some other parts of the work. The crank, with paddles in D, is to stir the mash up, so as to keep it uniformly mixed and heated.

Fig. 35.



SIEMEN's still, Fig. 34, is much used in Germany for the distillation of brandy. It consists of two stills, which can be used alternately. Both are bedded in the steam boiler, L. M M are the two stills; N is the rectifier of the wort-warmer; O, Q, the dephlegmator; P, a cylinder in which the condensed steam is collected for return to the boiler.

The preparer is filled with mash liquor by the pipe *o*; this again supplies the two stills by the pipes, *b b*. The refuse is withdrawn by the pipe, L (Fig. 35). From the boiler proceeds a perpendicular pipe provided with three taps, *q*, *r*, *s*, whose openings are so arranged that the steam can be directed into either still at pleasure.

The wort-warmer is shown in section in Fig. 35. It consists of an iron rectifier, or low-wine receiver, N, in which is suspended the lower part of the wort-warmer, the two vessels being bound together by bolted flanges, *g*. Steam from the tap, *s*, enters *n* through *c*, a small vessel for collecting the condensed steam, whence it is led by the pipe, *l*, into P, and thence to the boiler: *c* is covered with a finely perforated plate, to prevent sediment falling through. The vapours proceed through the tube, *e*, to the vessel, R, in which is collected the condensed liquor from the dephlegmator, Q, and then through the tube, S, to a condensing worm. The hot water from the dephlegmator is returned to the boiler by means of the tap, *w*. The tap, *t* and *t*, allows condensed water to enter the boiler.

The distillatory apparatus of Alègre is described in the Figs. 36 and 37.

Fig. 36 is an elevation of the distilling apparatus on the furnace side, and Fig. 37 a section made parallel to the visible part of Fig. 36. In these figures, A is the brickwork inclosing the fire and part of the lower boiler; B, the door of the furnace; E, the lower boiler, part of which is encased in the brickwork. F is a pipe issuing from the bottom of boiler, E, furnished with a stopcock, and serving to discharge the liquid that remains after distillation, or whenever required. *g* is a pipe and stopcock, by which the proper height of liquid to be introduced into the boiler is regulated, as shown by the dotted line, *h h*, in the section. I and C, manholes closed by a slide plate firmly fixed in its place by bolts, or by a screw-cap, for cleaning the boiler when necessary. *k* is a pipe and stopcock for ascertaining when all the alcohol has been separated from the liquid in the boiler, E.

Fig. 36.

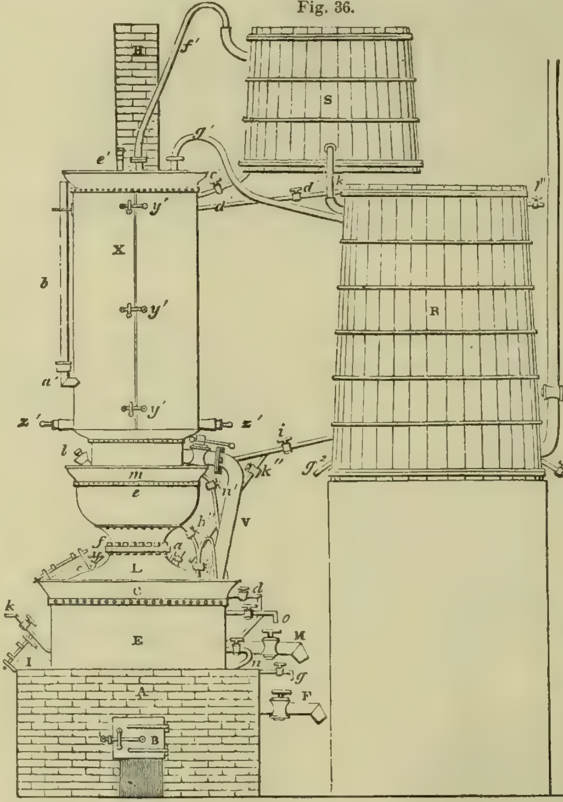
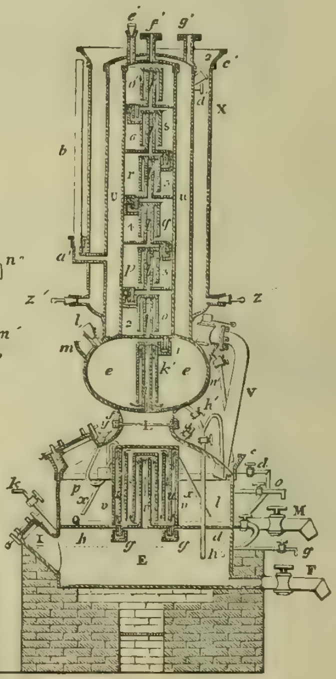


Fig. 37.



L is another boiler placed upon E, and which is emptied when requisite by the discharging-pipe and stopcock, M. Both these boilers are connected by the pipe, *n*, to which a stopcock is affixed. *o* is an overflow-pipe and stopcock, serving to regulate the height to which the liquor should rise in the boiler, L, as is shown in the sectional figure by the dotted line, *p*. Q is the stout plate or division between the boilers, E and L; in the middle of this bottom is an opening, on which is fixed the pipe, *r*; this pipe is open at both ends, and passes up through the liquid in the boiler, L, towards its neck; *s* is a hollow cylinder, which is inverted upon the pipe, *r*, and having its closed end uppermost. The open end rests on three small supports, fixed equidistant from the pipe, *r*, and elevated one inch above the bottom of the boiler, L; *t* is a third hollow cylinder issuing from the bottom of the boiler, L, and rising perpendicularly till it terminates in an open end, about one inch above the closed end of the hollow cylinder, *s*, which it surrounds; *u* is a fourth hollow cylinder, placed in exactly the same position as the cylinder, *t*, and enveloping all the foregoing; the closed end being topmost, and the lower open extremity resting upon three elevations of one inch in height, and equidistant from the cylinder, *t*. A distance of half an inch is left free between its closed end and the orifice of the cylinder, *t*. *v* is a fifth hollow cylinder, which incloses the whole of the others. Its lower extremity is fixed in the bottom, Q, of the boiler, L, and its upper extremity is attached to the closed end of the cylinder, *u*. These cylinders open alternately at the top and bottom, and by this means a passage is made for the vapour over each cylinder in succession. *x x* are tubes issuing from the top of the cylinder, *v*, at an angle of about 45°, and descending to within two inches of the bottom of the boiler, L; these tubes are open at both ends, and serve as valves to close the cylinders, *v* and *u*. Three of them are provided, which are fixed at the angular points of an equilateral triangle, supposed to be inscribed in the circular plane of the closed end of the cylinder, *v*; in the figure only two of these appear, the third being in the segment which is removed.

The safety tube, *y*, is for the purpose of preventing the influx of the liquid in the boiler, L, through the open pipes, *x x*, into the cylindrical spaces in the interior of the enveloping cylinder, *v*. Its upper extremity, which is funnel-shaped, is open to the air, the other end is in communication with the spaces in the interior of the cylinders, *v* and *u*, by passing through the closed end of the cylinder, *v*. This tube is curved so that, at or near its middle, it dips into the liquid in the boiler. In the part ascending from this curvature to the top of the cylinder, *v*, is a bulb or enlarged portion, *z*, which holds about a gallon of water introduced through the funnel-opening, *y*; *a* is a stopcock, which enables the operator to know the state of the distillation in the boiler, L, and is similar to *k* in boiler, E.

C is a circular basin placed upon the neck of the boiler, L, forming a refrigerator; *d*, a pipe and stopcock, which conveys heated water from the basin, C, into the lower boiler; *e* is a vase of an elliptical form, joined to the neck of the upper boiler by a bracket and rivets, as seen at *f*; *g g* are two tubes descending from the hollow cylindrical vessels inclosed in *v* into two small vases, or circular vessels. By these pipes the liquor condensed in the passage of the vapour over the cylinders is returned to the lower boiler, E; the small vessels act as water stopcocks, and prevent any vapour passing up by these tubes. *h′* is a tube having two stopcocks, and branching a little below the upper stopcock; by this tube the liquid condensed in the oval vase, *e*, is conducted at will into either of the boilers by opening the proper stopcock. The tube, *i*, rising vertically through the vase, *e*, to within one inch of the upper part of the vessel, is closed at the top by a plate and a hollow cylinder, *k′*, whose closed end is uppermost, and rests upon *i*. The open end of the cylinder, *k′*, terminates about one inch above the bottom of the vase, *e*. The upper part of the pipe, *i*, is pierced with a number of small holes, through which the vapour passes into the vase; *l* is a tubular opening in the elliptical vase, *e*, by which it is cleaned; this opening is closed by a wooden plug; *m* is a circular basin containing cold water, placed upon the vase, *e*, and acting as a refrigerator, and which discharges its hot water by the pipe and stopcock, *n′*.

The cylindrical column contains six compartments, or diaphragm rectifiers, *o p q r s o′*, placed one above the other; these diaphragms communicate with one another by means of six small tubes, *l′ l′ l′ l′ l′ l*, placed in their centres. The tubes are arranged similarly to the tube, *i*, in the vase, *e*, the upper part of each tube being closed, and enveloped by an inverted cylinder in the form of a hat, descending to within an inch of the bottom of each diaphragm. The *l′* tubes are perforated in the upper part, to allow the vapour to pass off, and a small pipe descends alternately at either side of the column from each compartment into a small trough or dish, 1, 2, 3, 4, 5, 6, similar to those seen at *g g*, in the lower boiler, E. By these pipes the watery liquid condensed in each compartment descends into that which is immediately beneath it, until it finally reaches the elliptical vase, *e*, and thence by the double-stopcocked pipe, *h′*, is conducted into either of the boilers at the pleasure of the operator. Hence the condensed liquor, whilst descending, offers no obstruction to the ascending alcoholic vapour. A long vertical hollow cylinder, U, envelopes the six compartments, *o p q r s o′*, at a distance of 6 inches. Water is introduced into this space, and thus the cylinder, U, acts as a refrigerator to the interior column.

The hot water is discharged from the refrigerator into the upper boiler by the large pipe and stopcock, V. X is a cylinder resting upon the projecting edge attached to the cylinder, U, which serves as its base; it is made to open and shut by the latches, *y′ y′ y′*. The space between this envelope and the cylinder, U, is used to torrefy the malt previous to grinding. The cover of the envelope is perforated with small holes, to give passage to the vapour evolved from the heated grain. *z′ z′* are two apertures by which the grain is withdrawn when properly dried. *a′* is a tube communicating with the interior of the refrigerating cylinder, U, bent upwards at right angles; at a short distance above this angle the tube is enlarged, forming a receptacle for the glass tube, *b*, serving as a gauge to show the height of water in the refrigerator. *c′*, a tube with stopcock, by which the fermented liquid is conveyed into the refrigerator when it is desired to carry on the distillation with the assistance of the cylinder, U, in conjunction with the boilers. Whether the liquid to be distilled be wine or wash, it is invariably heated here, so that it may be afterwards let down into the boilers at nearly a boiling temperature, by the large tube and stopcock, V, and the smaller one, *h′*. *d′* is a pipe and stopcock, by which wine may be introduced in the same way as the wash from grain by the pipe, *c′*, when that liquid has been employed in the course of operation. *e′* is a tube by which water is allowed to enter the rectifier for the purpose of cleaning it. *f′* is a tube, which conducts the rectified spirituous vapour from the summit of the column to the condensing worm in the superior condenser, S. *g′* is a small tube, conducting the vapour arising from the liquid in the refrigerator, U, into a small worm placed in the large condensing tun, R, collaterally with the large one. The chimney has a damper to regulate the draught from the furnace, B, which must be diminished during the charging of the apparatus.

When the apparatus is prepared, as seen in the figure, all the stopcocks are shut, excepting the overflow-pipes, *o* and *g*, which are left open.

The commencement of the operation is the filling of the large condensing vessel, R, with water, after which the superior large tub, S, is filled with wash liquor, or wine, as the case may be. This tub contains a condensing worm, wherein the vapour arising through *f′* is partly condensed, and which is connected to the large worm in the principal condenser, R, as seen in Fig. 36, by the pipe, *k′*. After S has been replenished with liquor, the lower boiler, E, is filled with water through the tubular opening, I, then the fire is lighted and the distillation of the water proceeded with, till the liquor in the vessel, S, acquires a temperature of about 100° Fahr. (37°·7 C.). As soon as the steam from the boiling water ascends to the upper boiler, the stopcock of the tube, *c′*, connecting the vessel, S, and the refrigerating space inside the cylinder, U, is opened, and the liquid allowed to flow in until the remaining liquor in the vessel also reaches 100° Fahr. (37°·7 C.). When this happens, the cock of *c′* is closed, and the vessel, S, replenished with more of the liquid. Both the stopcocks of the pipe, *h′*, are next opened, in order that the water condensed in the diaphragms of the rectifying column, as well as in the elliptical vase, *e*, may pass into the boilers; the stopcocks, *i*, *k″*, are at this time likewise opened to fill the refrigerating circular basins, C and *m*, attached to the upper boiler and vase, *e*. When these are full the cocks are closed, and the fire slackened by throwing on some moist small coal or wood, and inserting the damper. Water is first distilled in order to wash the interior of the apparatus, and to heat the liquor in the cylinder, U, and the vessel, S. The stopcocks of the pipes, F, *g*, *n*, are opened in order that the water contained in both boilers, as well as in the elliptical vase, may flow out by F. During the escape of the water the plate closing the tubular pipe, I, is withdrawn, and a broom or mop introduced to clean the bottom of the boiler. When the apparatus is newly erected this distillation of water is necessary to purify the interior from rosin and other matters proceeding from the soldering, &c.; but in other cases it is not requisite, except when impurities collect in the boilers or rectifying diaphragms, or when the distillation has been suspended for some days, or after repairs. It is customary to fill the whole apparatus with water when not required for use, in order to prevent the formation of acid, which would act on the various boilers and other parts of the whole still; the water is drawn off when operations are on the point of recommencing.

The boilers being empty, the stopcocks F and *n* are closed, and the lower boiler filled with water, until it flows out by the pipe, *g*, which is at this time closed, as well as the opening, I, and the stopcocks in tube, *h′*. The fire is then hastened by withdrawing the damper; and during the time the liquid in the lower boiler is rising to 212° Fahr. (100° C.), the stopcocks of the pipe, V, and of the overflow pipe, *o*, are opened, and the heated alcoholic liquid in the refrigerating cylinder, U, admitted, until the boiler, L, is filled, which is indicated by the liquor flowing out through *o*. These tubes are then closed, and the tube, *c′*, opened to refill the cylinder, U, with the spirituous liquor from the vessel, S, to the proper height, as indicated by the glass gauge pipe, *b′*, after which the cock of the pipe, *c′*, is shut. It is specially necessary that the water in the large condensing vessel, R, should be thoroughly cold. This is effected by opening the stopcocks, *l″* and *n″*. By turning the stopcock, *n″*, the cold water from the reservoir, which should be erected at an elevation, and convenient to the place for the use of the apparatus, flows into the lower part of R, and the hot water is discharged through the pipe, *l″*, at the same time by the influx of cold water beneath. Matters being thus in readiness, the vessels are charged, and while doing so the fire is briskly urged; the water of the lower boiler soon reaches ebullition, and the liberated steam, coming in contact with the bottom, Q, of the upper boiler, heats the spirituous liquor which it contains. As the steam is generated in greater abundance, it rises through the cylindrical pipe, *r*, and thence descends and ascends alternately in its course over the other successive cylinders, till it escapes by the open ends of the three diverging pipes, *x x x*, immersed in the liquid contained in the upper boiler. During this complicated course of the steam the contents of the boiler, L, are raised to ebullition. By this means alcoholic vapour is evolved through the pipe, *i*, and after traversing the elliptical vase, the uncondensed portions ascend into the six diaphragms, *o p q r s o′*, in the rectifying column, by means of the communications, *l′ l′ l′ l′ l′ l′*. Here the rectification is principally carried on; some of the aqueous portion of the vapour is condensed in each compartment till the spirit reaches the top of the column, from which it is carried off by the pipe, *f′*, into the coiled portion of the large worm, deposited in the vessel, S, where it is perfectly condensed in its course through this and the other worm in the large condenser, R, and flows in a fine stream into the appropriate backs, or spirit vats, placed below the protruding end of the worm at *m′*. The weak spirit from each compartment of the steam rectifier returns by the small pipes, 6, 5, 4, 3, 2, 1, till it descends into the elliptical vase, *e*, and thence through the pipe, *h′*, into the boiler, L. As the distillation advances larger quantities of vapour rise from the heated liquor, both in the boiler and oval vessel, *e*, as well as in the lower compartments of the rectifying column, the condensed water from it always descending, while the distillation of the alcoholic liquor continues to afford alcoholic vapour. When on opening the test-cock, *a*, and applying a light to the vapour, it inflames, there is still some alcohol in the liquid in the boiler, but if it does not ignite, the whole of the spirit has been eliminated; the firing is then finished, and another charge begun. The distillation of the first charge requires a period of three hours, on account of the boiler being filled with cold water; but in each succeeding operation only two hours are required, as all the parts of the apparatus, with the water in the lower boiler, are hot.

After the whole of the alcohol has been expelled, the boiler, L, is emptied and thoroughly cleansed. The opening, *c*, and the stopcock, M, are then shut, and the cock, V, opened, in order to allow the heated liquor from the refrigerating compartment in U, to flow in to refill the boiler. When the liquid has risen to the level of the pipe, *o*, the cock, V, is shut, and the communication between the refrigerating cylinder and the vessel, S, containing the liquid to be distilled, is opened by turning the stopcock, c', and the cylinder refilled to the proper height, as indicated by the gauge pipe, b'. The connecting-pipe between the vase, *e*, and the under boiler, is opened by turning the cock, h', and closing the lower one with which this pipe is supplied, in order that the liquor collected in the vase during the distillation of the preceding charge may flow into the lower boiler, whose overflow pipe, *g*, should be opened to indicate when it is full. If the quantity be not sufficient to fill the lower boiler, liquor is allowed to flow in from the refrigerating basin, C, attached to the upper boiler, by opening the stopcock, *d*. As soon as the liquid flows out through the pipe, *g*, the stopcock of this, as well as the cock of the pipe, *d*, is closed, and the fire stirred. Shortly afterwards, when the steam from the lower boiler rises through the apparatus, the stopcock of the pipe, n', is opened, that the hot water contained in the refrigerator, *m*, may descend to that attached to the boiler, L. After the whole of the water is run down, the tap, n', is shut, and *i* and k'' opened, to replenish both the refrigerating basins with cold water from the large condensing vessel, R. The second firing is about this time in progress, the liquid in the boiler is deprived of its alcohol in the manner as before explained, and the distillation of the charge is completed in about two hours. A similar mode of operation to that described takes place at each charge, irrespective of the alcoholic liquor submitted to distillation.

MILLER, of Glasgow, patented a still, the novelty of which lies in the employment of evaporating cones, having open spiral channels winding round their exterior. In other respects the still embodies the main features of all the principal distilling arrangements already described—namely, that of returning the products of the first condensation, which contain an excess of water, to the body of the apparatus for further rectification.

Fig. 38 shows the principal parts of the still and worm; Fig. 39, a sectional view of the cone. A is the body of the still or boiler, which is of ordinary construction. The head of the still, A′ A′ A′, consists of three cones, placed concentrically, B, C, D, but a small distance apart. The surfaces of the cones, B and D, are plain, but round the exterior of the cone, C, an open spiral channel, X, winds from the top to the base. The position which this part occupies may be better understood from the detached view of the cones in Fig. 39, where X X shows the channel, and C the cone. A pipe, E, leads from the annular space between C and D to the wash-heater, F, which consists of a vessel filled with a number of small parallel pipes, and communicating with a low-wine condenser, G, which is placed in the upper part of the worm tub. The wash is supplied to the vessel, F, by a wash-charger reaching from the backs, and communicating with the vessel, F, at M; this, however, is not shown in the figure. I is a pipe which leads from the top of the outer cone, B, to the spirit condenser, K, which consists of a cylindrical case, inclined towards the still, and containing a number of pipes laid longitudinally, through which the gaseous products pass; it is filled with water supplied by a pipe not seen in the figure; the heated water is discharged through the pipe, Q. The pipe, K′, issues from the end of the spirit condenser, and enters the refrigerator, where it is united to the worm, L, placed in the bottom of the tub, W. O and *i* connect the condensing pipes in the vessels, K, F, and low-wine condensing worm, G, with the outer part of the cone, C; and the pipe, H, serves as a communication between the top of the wash-heater, F, and the body of the still, for the purpose of charging the latter.

The following is the mode of working:—A quantity of wash is run into the still, A, from the wash-heater, F, through the pipe, H, to the height of say 3 or 4 inches. As the wash boils, the vapour arising from it ascends the space in the still head, A′A′A′, between the cones, C and D, and through the pipe, E, into the wash-heater, F; part of the vapour is here condensed, at the same time heating the liquor contained in the vessel, and the remainder passes off into the low-wine condenser, G. The condensed liquor in F, as also that which is formed in G, returns through the pipes, *i*, J, into the top of the space, B and C, in the still head, and flows into the channel, X, where it is reheated in its descent through this compartment to the base of the cone, by the simultaneous ascending vapour between C and D, and the portion thus evaporated flows off through the pipe, I, to the spirit condenser, K. That portion of the liquid which is not converted into vapour is ejected from the cone, and received into the boiler through a pipe, P, to undergo another distillation.

In the spirit condenser, K, a further rectification takes place; all the finer parts of the spirit pass off through the pipe, K′, into the worm, L, where they are condensed and afterwards discharged through R into the spirit-back, while the coarser products return through the pipe O, into the canal, X, for further purification. Whatever be the quantity of wash which is introduced at first into the still, no more should be allowed to enter till the whole of its alcohol is expelled. For this end the supply pipe, H, is furnished with a stopcock, N, and a branching pipe, S, for the purpose of drawing off any excess of wash into a tank appropriated to that purpose. Towards the end of the distillation, the weak faints may be run off from J, by means of a branch pipe, V, that enters the large condensing worm.

At Bushmills, in Ireland, a noted whisky is made exclusively from malt, which is prepared in the ordinary way, excepting that peat is used in drying it. The quantity of malt wetted for each brewing is 80 bushels, from which only one mash is prepared for fermentation, the after-washings being retained, as usual, for exhausting fresh quantities of malt. In preparing the first mash, from 18 to 20 gallons of water are used to each bushel of malt. Only as much water or small worts is run on as will wet throughout the whole of the malt, the temperature being 146° Fahr. (63°·3 C.); in about fifteen minutes afterwards the remaining quantity is run on at a heat of 155° to 160° Fahr. (68°·3 to 71°·1 C.).

After drawing off the first mash, 900 gallons of water are let down into the grist at a temperature of 170° to 175° Fahr. (76°·6 to 79°·4 C.), and after mashing for three-quarters to one hour and a quarter, the wort is let into the under-back, and pumped into the coppers: 900 gallons more are used in the third mash, the temperature being 180° Fahr. (82°·2 C.); both these liquids are used in making the first mash on the next day's brewing, and on account of the density of the small worts, the malt used is from 65 to 70 bushels.

The density of the first mash, when let into the fermenting tun, is 50 lbs. to the barrel as usual. None but the best of barm is employed in the fermentation; the quantity is 1 per cent. of the wort, one-half of which is added at the commencement, and the other when attenuation has reached 30 to 35. Attenuation is usually completed in forty-eight hours, though in variable weather a longer time is required; the quality of the malt also affects the quickness of the decomposition, but the chief cause of a good or bad fermentation is the yeast; the fermented worts are reduced in gravity to that of water, and frequently below this. The mash stills at the Bushmills factory are of the old description, and the manager states they are the best for making fine spirit, an assertion with which many will coincide.

Fig. 38.

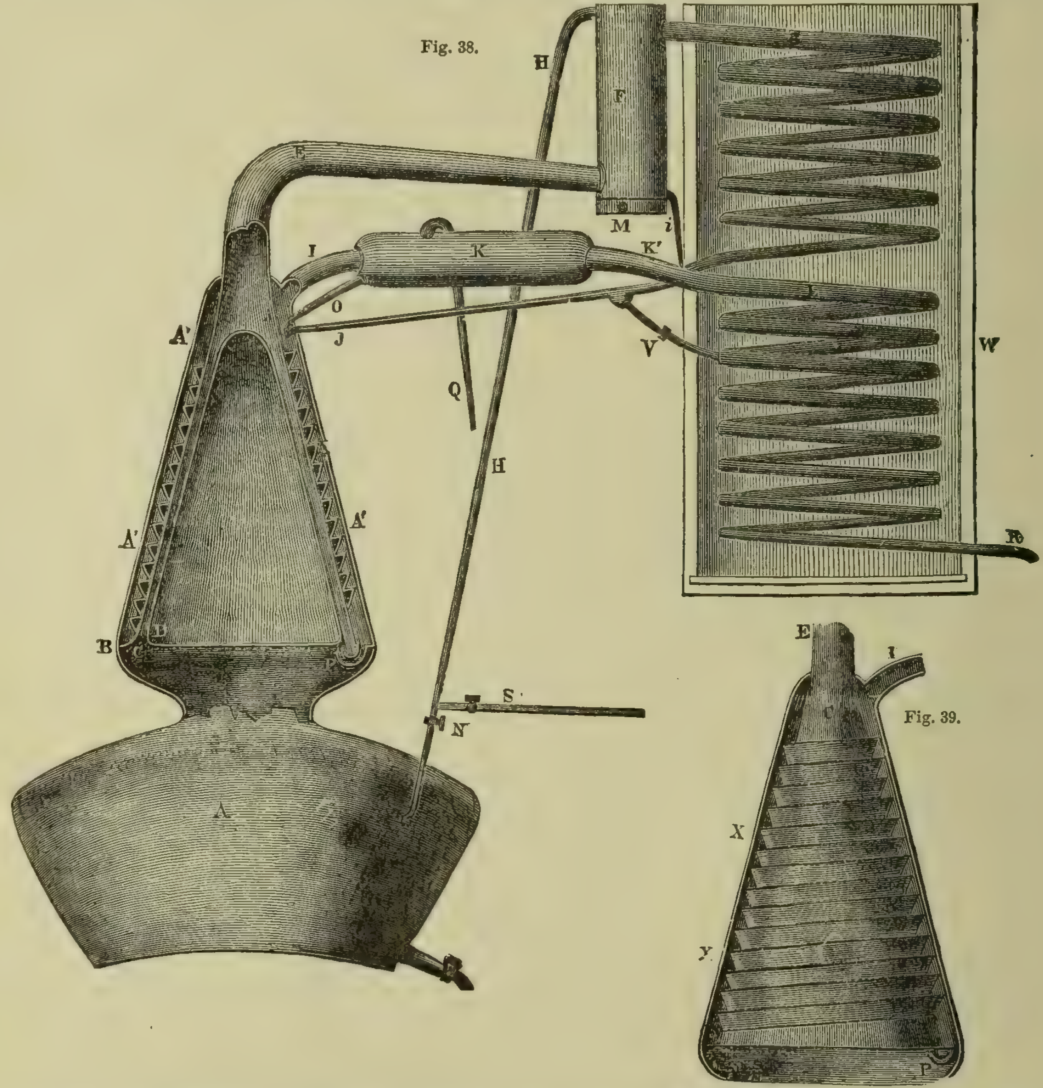


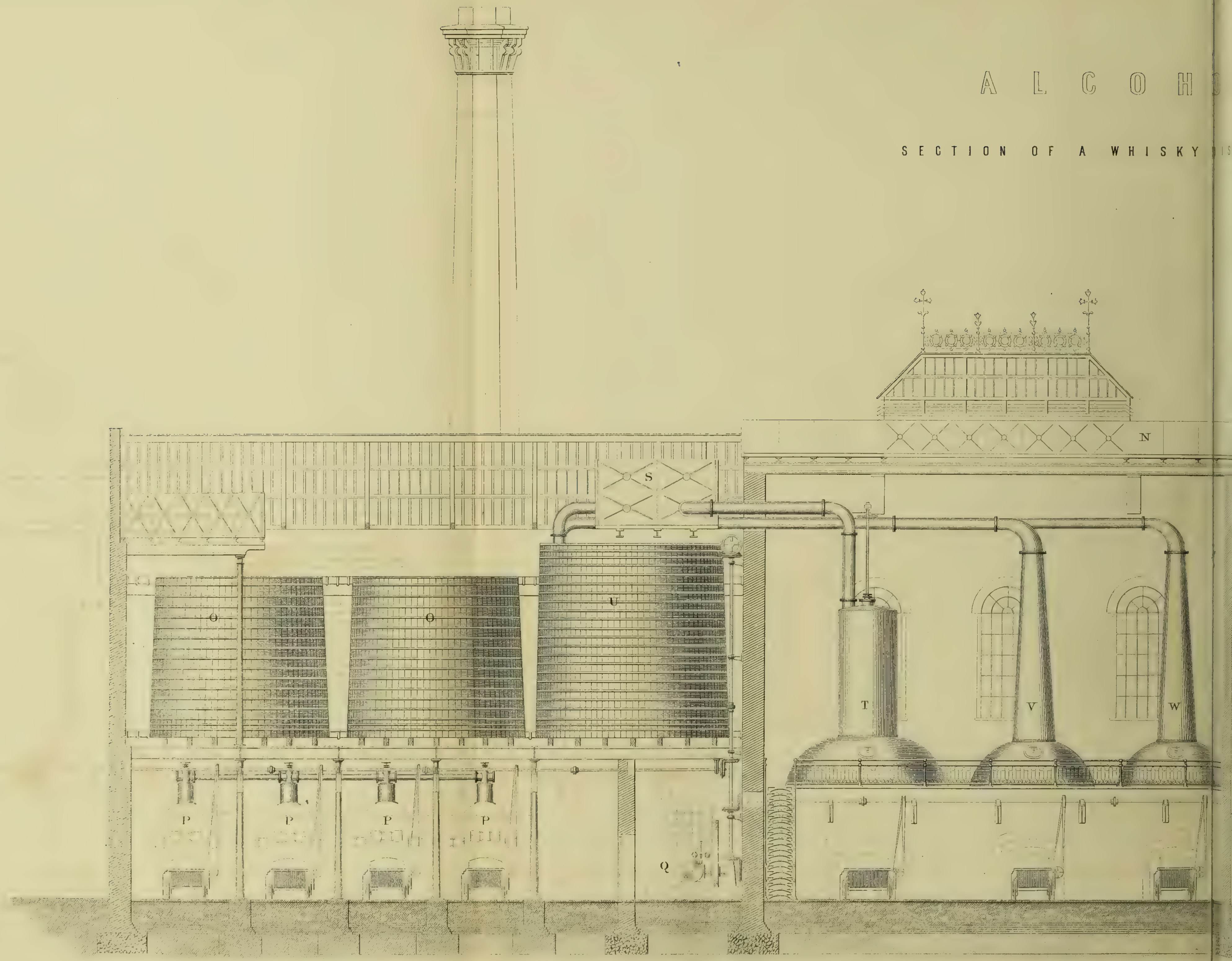
Fig. 39.

The average yield in this establishment is from 14 to 16 gallons per quarter of 8 bushels, but there is always a variation above or under these figures, according to the quality of the grist. The best spirit is made always in dry weather.

Whisky Distillery.—An Irish whisky distillery of the most modern construction is shown in "Al-

ALCOH

SECTION OF A WHISKY



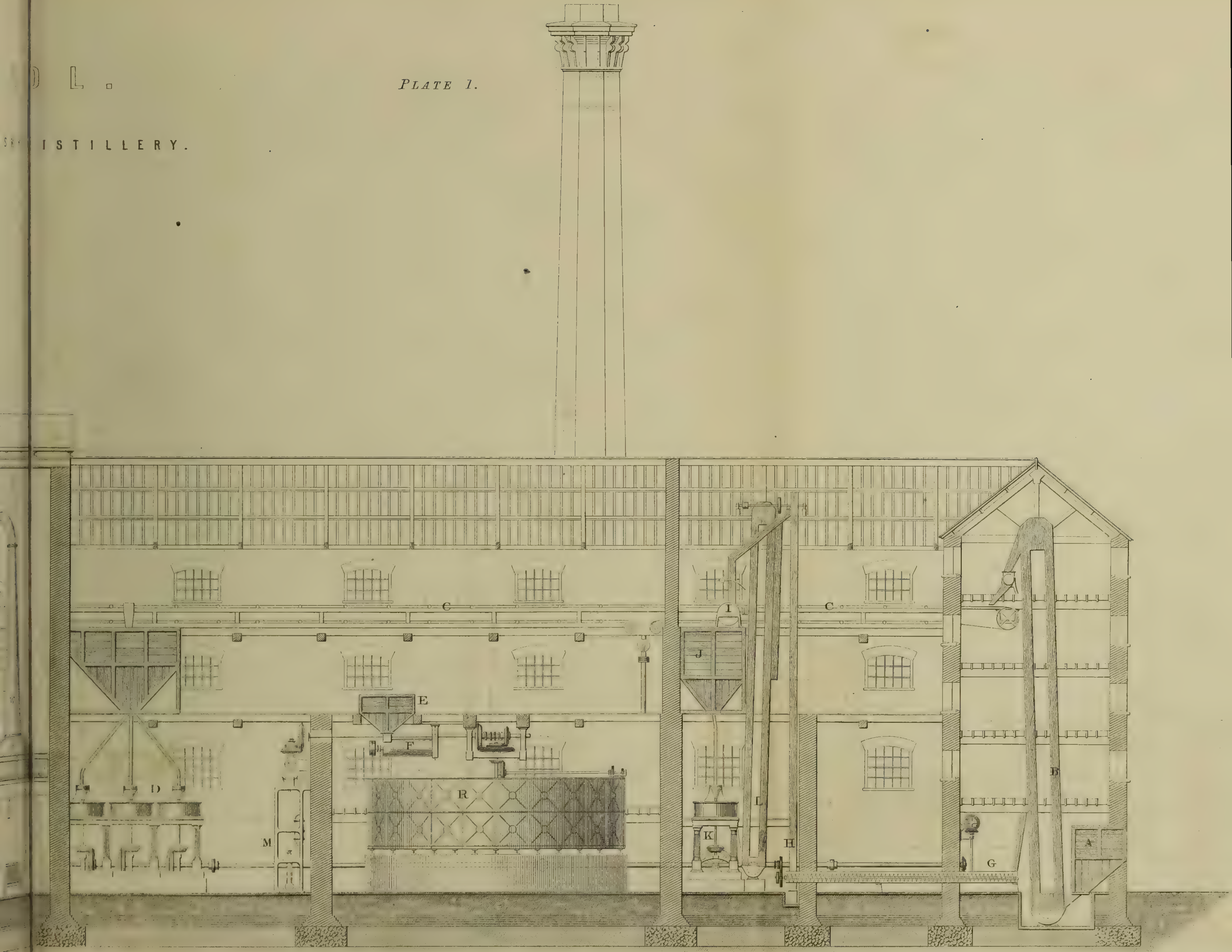
J. B. LIPPINCOTT

A *Hopper.* B *Elevator.* C *Corn Conveyor.* D *Millstones.* E *Grist Case.* F *Seel's Mashing Machine.* G *Malt Sc*
N *Water Tank.* O *Boiling Tubs.* P *Steam Boilers.* Q *Steam Engine.* R *Mash Tun.* S *Wash Charger or Heater.*

D L.

ISTILLERY.

PLATE 1.



0. PHILADELPHIA.

H *Elevator.* I *King's Grain Measurer.* J *Malt Hopper.* K *Millstones for Malt.* L *Elevator.* M *Pumps.*
Wash Still: U *Worm Tub.* V *Number one low Wines Still.* W *Number two low Wines Still*

cohol," Plate I. This distillery has been erected at Banagher, King's County, Ireland, for the Banagher Distillery Company (Limited), under the auspices of Sir SILLS JOHN GIBBONS, Bart., the chairman; Mr. J. T. CROSTHWAIT, the resident engineer; and Mr. W. PEACEY, the manager and distiller. It is probably the largest whisky distillery that has been as yet erected, and is capable of producing over half a million gallons of whisky per annum.

The engraving represents a longitudinal section, in which most though not the whole of the utensils is shown. By the aid of the following description by F. PONTIFEX (who constructed the machinery), it will easily be understood:—

"The first part of the operation of whisky distilling is very similar to that of brewing beer, and the reader is referred to the article on BEER, in which will be found detailed descriptions of all the utensils and machinery common to the two processes. It may be mentioned that the 'pot still' system here described is used only with the best grain: it produces a spirit which retains the flavour of the grain throughout, and does not require any addition of essences. COFFEY'S patent still (which see) is used with inferior grain, and produces at one operation a strong neutral spirit, which is, however, generally deficient in character and flavour.

"As described in the early part of this article, whisky is made partly from malt and partly from unmalted grain, and the excise laws compel the two to be ground apart. The grain stores are in the engraving on the right. The grain is first brought in at the hopper near the ground. It is raised from floor to floor by the elevator, which runs up through the middle of the building, completely to the top, so that it can deliver the grain to either of the floors. The unmalted grain is stored on the top floor, and when required for use is conducted by the horizontal 'corn conveyer,' which runs in through the upper part of the distillery from the corn stores to the millstones, of which there are six pairs (three pairs only are shown) close to the still-house. The 'corn conveyer' is an endless band of india-rubber or webbing, running on rollers, but not having such buckets as the elevator has.

"The millstones are precisely similar to those used for grinding corn into flour, and in this respect the present operation differs from that in beer brewing, as in the latter the malt is only crushed between smooth rollers, and not ground. When the grain is ground, it is raised by an elevator (not shown) to the floor above the mill stones, and thence conveyed in sacks, as required, to the hopper or 'grist case' attached to a STEEL'S mashing machine (for description, see BEER) over the mash tun.

"From each floor of the corn-store on which malt is kept, there is communication by a hopper and shoot to a malt screw, running horizontally near the ground from the corn store to another elevator, by means of which the malt is raised to near the top of the building, and thence falls to the KING'S grain measurer, which gauges the quantity (see BEER), and into the hopper over those millstones which are specially used for malt. There are two pairs of these stones. The ground malt is again raised by another elevator, running by the side of the one last mentioned, and delivered to either of the two floors shown, from which it is conveyed to the STEEL'S mashing machine in the same manner as the unmalted grain.

"Having now brought the grist to the point ready for mashing, the provision for the water supply must be referred to. In the Banagher distillery there are five sets of three-throw pumps (a side view of one set being shown near the mash tun). Two sets of these pumps are used for water, one set for wash, one for faints, and one for spirits. The water is pumped from a well into the large iron tank that forms the roof of the still house, an opening being left in the middle with a lantern roof for light and ventilation. This tank holds about 70,000 gallons.

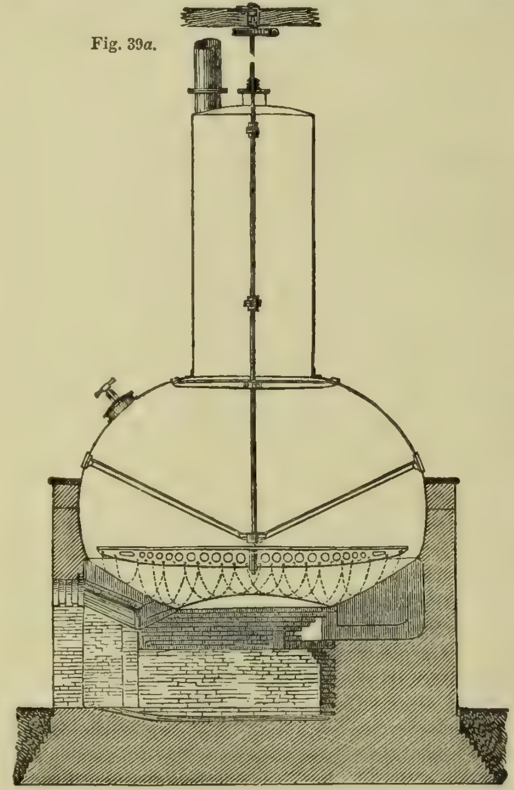
"From this huge vessel the water runs to three boiling tubs, two of which are shown on the extreme left of the engraving. Each holds about 35,000 gallons. Below the boiling tubs are shown four steam boilers, each of about forty horse-power, which are heated by JUKES' revolving furnaces. These boilers provide the steam for driving the steam engine (shown near the boilers) and for heating the water for mashing. Each boiling tub has in it a perforated copper globe connected with the steam boiler, into which the high pressure steam is brought and injected direct into the water through the perforations. The hot water, when at the right temperature, is conducted from the boiling tubs to the mashing machine and mash tun. The ground corn or 'grist' and the hot water pass together through the former and fall into the latter.

"The mash tun (there are two of them) is made of cast iron, 30 feet in diameter and 8 feet deep, and holds more than 35,000 gallons. It is fitted with a false bottom, and an internal mashing machine similar to those used in breweries. After mashing, the extract or 'wort' runs into the under back (a cast-iron vessel holding about 10,000 gallons, not shown in the engraving), and is pumped into the wash backs, seven in number, containing about 36,000 gallons each. The wash backs are simply wooden tubs similar to the boiling tubs. Here the proper proportion of yeast is added, and fermentation is continued until the wash is ready for distillation. So far the operation is much like the brewing of beer, except that the wort is not boiled. All the appliances hitherto mentioned are more fully described in the article BEER.

"Distilling proper is conducted as follows:—The wash having been perfectly fermented is run into the wash charger (a cast-iron tank not shown on the engraving), from which it is pumped up into the intermediate wash charger or heater, the cast-iron tank above and just to the left of the stills. The arm pipe (that is, the pipe leading from the still head to the worm) of the wash still passes through the intermediate wash charger, taking one turn inside it, so that the hot vapour from the still on its way to the condensing worm communicates some heat to the wash that is to be used for the next distillation. From the intermediate wash charger the fermented and partially heated wash runs into the wash still, which is made of copper, and contains about 20,000 gallons. This still is furnished with a revolving furnace similar to those applied to the steam boilers; and it may here be mentioned that the other two stills have similar furnaces.

" Fig. 39*a* is an illustration of the wash still, showing the 'rousing' apparatus inside. If not agitated, the thick particles of the wash would settle on the bottom of the still, and cause it to burn; therefore, while distillation is going on the 'rouser' is revolved, and the chains attached to it sweep the bottom of the still, and keep its contents in motion. The still head is a large copper cylinder, and from the top of it comes the copper arm pipe, which passes through the intermediate wash charger, and continues to the condensing worm, which is a coil of copper pipe immersed in cold water in the worm tub (this is the third vessel from the left of the engraving, next to and larger than the two boiling tubs shown). The vapour arising from the still is condensed in this worm, and runs out into a copper vessel called the 'safe.'

Fig. 39*a*.



"This first product is called 'low wines,' and is pumped into wooden vessels (not shown) called 'low-wines receivers;' from there it passes to the second, or 'number one low-wines still.' It is there distilled again, and again condensed as before described, and this second product is the 'faints.'

"The 'faints' are pumped into wooden vessels called 'faints receivers,' from which they are run into the third or 'number two low-wines stills' to undergo a third distillation; the product of this still being 'Irish whisky,' which is pumped into vats, and matured until ready for market.

"The machinery is worked by a steam engine, and by a turbine (not shown in the engraving), and the whole arrangements are such that hand labour is almost entirely dispensed with. The pipe connections between the various utensils, as well as the shafting, &c., for driving the machinery, are very considerable in a distillery of this size, but cannot be shown in the engraving."

In all modes of conducting distillation, it is important to bear in mind that the fermented mash is a mixture of volatile and non-volatile substances, and that the object in view is to separate one of the volatile substances only (the alcohol) from all the other bodies present. The non-volatile matters are the malt, husks, and fibre, various inorganic salts, undecomposed yeast, lactic acid, succinic acid, glycerine, &c. The volatile are mainly alcohol, water, acetic acid, and fusel oil. The difficulties encountered in separating the water have been fully described, and likewise the means now adopted for overcoming them; but in endeavouring to obtain the largest possible yield of spirit, the distiller is apt to forget that he is doubling his labour by at the same time promoting the formation of that mixture of amylic, butylic, and propylic acids, which is commonly known as "fusel oil."

Ethylic alcohol, when contaminated with fusel oil in any considerable quantity, has a very unpleasant, nauseous, and fiery flavour, and besides acts upon the human system in a very injurious manner. The quantity present appears to depend entirely on the temperature at which the last part of the distillation has been conducted, since all the constituents of fusel oil boil at a much higher temperature than ethylic alcohol. Hence, if a pure spirit is desired, it is essential to avoid pressing the process too closely as it approaches its termination.

This is the more important as the complete removal of fusel oil is a matter of considerable difficulty, and indeed is seldom effected on the large scale. Repeated distillation fails to separate the ethylic from the amylic alcohol, though the former boils at 79° C. and the latter at 132° C. It is necessary to dilute the contaminated alcohol largely with water, and to collect only the strong spirit which first comes over, and to repeat the operation several times before even a tolerably pure spirit can be obtained. The expense and trouble of this operation is, of course, very great.

The amount of alcohol to be procured by the operations of fermentation and distillation depend not only on quantity of alcohol-forming constituents, that is, the starch, dextrose, or cane sugar, of the raw material employed, but also on the proper carrying out of the important operations of distillation, mashing, and fermenting, in properly constructed apparatus, and with due judgment and care.

Potteen Whisky.—This far-famed spirit was some time ago more extensively manufactured than at present. It seems to be more than ever prized on account of its scarcity, and bears a high price. The singular flavour of the Irish spirit is supposed to be caused by using turf to dry the malt. DONOVAN describes a potteen distillery he inspected in the south of Ireland. It was a place renowned for producing good whisky. The distillery was a small thatched cabin; there was a large turf fire kindled at one end, and confined by a semicircle of large stones, upon which a 40-gallon tin vessel, serving the twofold purpose of a water-heater and a still body, was resting. An orifice in the roof, immediately over the fire, served as a chimney for the escape of the smoke after it had traversed the apartment.

The mash tun was a cask hooped with wood, at the under part of which, next the chimb, was an opening plugged with tow. This vessel had no false bottom; in place of it young heath was strewn, and over this a stratum of oat-husks. Here the mash of hot water and ground malt was occasionally mixed up for two hours; after which time the vent at the bottom was opened, and the worts were allowed to filter through the layers of oat-husks and heath. Mashing with hot water on the same grains was then repeated, and the worts were again withdrawn. The two worts being mixed in another cask, some yeast was added, and the fermentation allowed to proceed until it fell spontaneously, which happened in about three days. It was now ready for distillation, and was transferred into the tin boiler, which was capable of distilling a charge of 40 gallons. A piece of soap, weighing about 2 ounces, was then thrown in to prevent its running foul; and the head, a large tin pot with a tube in its side, was inverted upon the rim of the body, and luted with a paste made of oatmeal and water. The lateral tube was then luted into the worm, which was of copper of 1½ inch bore, coiled in a barrel for a flake-stand. The tail of the worm, where it emerged from the barrel, was caulked with tow. The wash speedily came to the boil, and then water was thrown on the fire; for at this period is the chief danger of boiling over. The spirit almost immediately distilled; it was perfectly clear; and by its bead, this first running was inferred to be proof. Its flavour was really excellent; and it might well have passed for a spirit three months old. As soon as the upper stratum of water in the flake-stand became warm, a large pailful of cold water from an adjoining stream was dashed in with sufficient force to make the hot water run over, it being lighter; and this cooling process was continually resorted to. In this way the singlings were drawn off in about two hours, and those from four distillations made one charge of the still to produce the potteen.

The malt was prepared by inclosing the barley in a sack, and soaking it for some time in bog water, which is deemed the best; then withdrawing and draining it for some time, after which it is made to germinate in the ordinary way. When it has grown sufficiently, it is conveyed in a sack to the kiln. Besides the much-valued flavour of potteen, it derives a part of its character from being distilled entirely from malt. Frequently, however, about one-fourth of raw corn is added. From a bushel of this mixed grist the potteen maker obtains a gallon of spirit, of what he call three-to-one; or three glasses of spirit mixed with one glass of water afford proof spirit. This is, according to calculation, much below the produce that ought to be obtained.

The body of the still cost £1, its head 4*s.*, the worm cost £1 5*s.*, the mash tun and flake-stand, 12*s.*; £3 was, therefore, the value of the whole distillery. Sometimes, however, they are constructed on a more extensive scale. It is very doubtful whether the aroma depends on the turf smoke, for it is stated that the spirit has the same taste and odour when coal is burned under the kiln. It is possible that the turf smoke may be absorbed by the spirit, for it is well known that there is a period of the alcoholic fermentation at which odours are apt to be retained. The peculiar flavour more probably arises from the bog water in which the malt is steeped. When dried in the kiln after steeping, the heat is often sufficient to char the bog extract remaining in the malt; consequently, this would communicate an agreeable smoky aroma to the spirit.

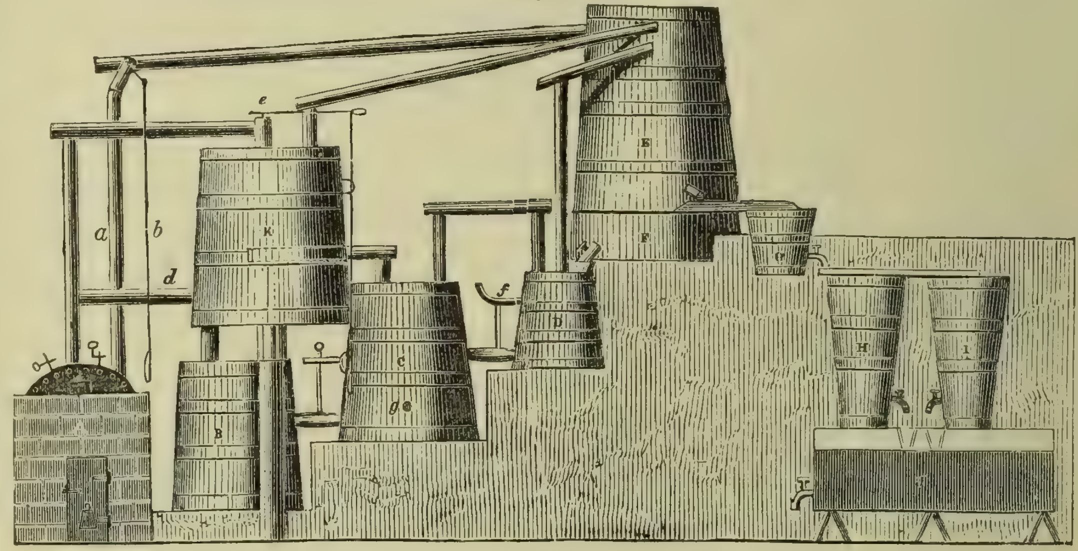
From a want of scientific knowledge and proper utensils, illicit distillers conduct their business in a different manner from that pursued by licensed traders. In preparing the malt, the sacks of barley are generally steeped in bog-holes or other places, where they remain forty-eight hours, or until completely saturated with the water. They are then drawn out and drained for ten or twelve hours. After this the grain is spread out upon the floor in a thick layer, and remains so till it begins to chip or germinate; it is turned occasionally, until all appears alike sprouted. It is afterwards spread by degrees, till such time as the buds show three points, and when these points have grown half way down the grains, by means of a regular heat, the particles are semi-transparent. At this stage it is spread thicker on the floor, and brought to a heat easily perceptible to the hand, then thrown into a round heap, and suffered to remain in that state for twenty-four hours, or longer; the latter is termed the rot or withering heap. It is then carried to the kiln and dried by turf; the kiln-head on which it is dried is covered with decayed straw, over which, if convenient, is placed haircloth or matting. The period of drying a kiln-head or crop, as it is termed, is commonly twenty-four hours, when directed by a person of experience. The grain, while on the kiln, is carefully turned, to expose every particle to the same heat, and to prepare it for coarse grinding. It is next taken to the still-house, which is usually a hovel or excavation near a running stream, or where there is a full supply of water. The quantity of malt to be brewed is commonly from 16 to 17 stones; after being bruised or mashed in the ordinary way, it is covered in the kiln with a lid or sacks, and suffered to repose for three or four hours. The worts are then drawn off, and cooled to a temperature regulated by the finger, no instrument being used for that purpose, and commonly to the same degree as that which is observed in regular distilleries; they are next put into a pipe or puncheon, with about a gallon of yeast; in an hour or two after the barm is added, fermentation begins, and in twenty-four hours afterwards the attenuation is considered complete. Sometimes two brewings, after undergoing the fermenting process for about eighteen hours, are considered fit for the still; and in the ordinary course of working a brewing is made every morning. The quantity of pure spirit drawn from these two brewings is usually 223 gallons, of one-to-two, or two-to-five; or, in other words, the spirit is of such a strength that it will bear 1 gallon of water to about 2 gallons of spirit, or 2 gallons of water to 5 of spirit, to bring it to proof. The usual strength at which illicit spirit is made, is from 4 to 6 over proof on Sikes' hydrometer; but sometimes it is as much as 8 per cent., and in many cases it has been sold at a strength of 30 over proof.

The flavour is entirely caused by the malt, and the mode of distilling.

In distilling the wash, the strong low-wines are separated from the weak, the latter being thrown back into the still with the succeeding charge of wash; a similar practice is observed in making spirit, the faints being put into the still with the next charge of low-wines. Thus the spirit is preserved pure and clear, nothing whatever being used in the distillation but a small quantity of soap thrown into the still with the pot-ale or refuse, to neutralize or keep down the yeast, as they term it, which would otherwise cause the run of the low-wines to become coloured like the wash, or to get foul. It is a mistaken notion to suppose that soap is used only by the larger distillers, since it is considered an indispensable article by every person who understands the mode of working a still on the old system.

Whisky is generally made in the United States from Indian corn; and in Cincinnati, where this grain abounds, there is so large a quantity manufactured as to supply the Western and Southern markets. In Pittsburg, and other parts of the United States, the whisky is purified by filtering it through charcoal coarsely ground.

Fig. 40.



Numbers of distilleries are now at work in Canada; they are mostly of wood, and worked by steam. The annexed drawing and description, Fig. 40, is of one near Toronto.

A is the brickwork, in which the iron boiler, with a cylindrical flue running through the centre, is partly inclosed. B and C are the first and second wooden stills, of the same size, being 4 feet 8 inches at bottom, and 4 feet 6 inches at top, with an altitude of 6 feet; D is the doubling or low-wines' still, 2 feet 10 inches at bottom, and 2 feet 4 inches at top, the height being 3 feet 9 inches; E is the worm-tub, 6 feet at bottom, 5 feet at top, and 9 feet high, supplied by a copious stream of water; F the low-wines' and faints' receiver; G is the recipient for the spirit previous to passing through the rectifiers or filtering vessels, H, I, and is 2 feet at bottom, 2 feet 4 inches at top, by 2 feet in height. The top diameter of H and I is 3 feet, and the bottom 2 feet, the altitude being 5 feet; they are filled with charcoal and other material, through which the liquor gradually descends in a limpid, gently-flowing current into J, the final receiver, or store cask. K is a tank or large vessel for holding warm water for distilling purposes, supplied from the top of the worm tub, the heat of which is supported by steam from the tube, *c*, connected with the boiler, and having a stopcock for regulation at *e*. The tank is a reservoir for supplying the mash tubs with water, of which, in the establishment, there are fourteen, each measuring 3 feet 4 inches by 3 feet 6 inches in diameter, ranged on a loft above the stills, in such a manner that, after the worts have undergone fermentation in these tubs, they are let down by a leader or trough into the second still, C, at *g*. When the first charge is worked off, the remainder is let into the first still, and the second still is charged from the mash-keeve. To facilitate the operation, there are pipes with proper stopcocks from still to still, such as that at *f*; and it will be perceived that the whole process of distillation is effected by means of steam admitted through the tube, *d*, projecting from the main upright pipe of the boiler into the first still, B, and so proceeding by other pipes through the other stills. The tubes which convey the steam into the stills descend to within 3 or 4 inches from the bottom.

All the vessels and pipes, as well as the stills, are made of pine; the pipes are 9 inches square, with a bore of 2½ inches in diameter. The steam-boiler is 7 feet deep, the height of which, at the fire place, is 8 feet, and it is supplied by water from the worm-tub by the pipe, *a*, regulated by a stopcock or ball of lead which is worked by the cord, *b*. It is not necessary to describe the other vessels of this arrangement, as they are similar to those employed in the distilleries of Scotland and Ireland. The greatest disadvantage attending it, is the liability of the timber vessels to become unserviceable when the operations are discontinued for any time; but in a country like Canada, where wood is plentiful, this inconvenience is readily repaired.

The wash is usually made from rye, wheat, or Indian corn, with a mixture of one-twentieth part of barley malt, or one pound to the bushel of mixed grain; many use a larger quantity. This is ground or crushed in a mill, and then mashed with water, at a heat ranging between 158° and 162° Fahr. (70° and 72°·2 C.); others work at a temperature so high as 180° and 190° Fahr. (82°·2 and 87°·7 C.), but this is unusual. When mashed, a cover is immediately put on the tubs, or keeves, in order to keep in the heat as much as possible. The mash is then permitted to remain, with an occasional agitation by the rakes for about two hours, until it acquires its proper sweetness; at this stage cold water is added to reduce the heat to between 70° or 74° Fahr. (21°·1 to 23°·3 C.) when yeast is added. The tubs or keeves are again covered and allowed to repose until completely fermented, when the distilling commences. The whole mash, grains and all, are put into the still. Brewing and distilling are generally carried on in the Canadas from October till May.

RECTIFICATION OF SPIRIT.—On recapitulating the steps through which the production of spirit has been traced, it will be seen that first the grain, or grain and malt, is crushed, in order to allow hot water to act more readily upon it; next, the mashing takes place and worts result; then the fermentation of the worts commences, and the saccharine matters are resolved into alcohol; finally, this alcohol is, by successive distillations, separated from its greater portion of water, and *plain British spirit* is obtained. Pure alcohol, the various forms of spirituous liquors known as hollands, whisky, gin, British brandy, and rum, and the cordials under the name of peppermint, cloves, aniseed, &c., are produced by the rectifier, from the plain spirit purchased from the distiller. British spirit in the form in which it leaves the distillery is but little known.

The manufacturer of whisky, or any of the other alcoholic liquors, rarely purifies the products, but disposes of them to the rectifying distiller, whose business it is to remove from them those contaminations which render them disagreeable or injurious. If, however, the fabricator conducts this operation as well as the original preparation from the grain, a distinct part of his premises has to be allotted to the work, to comply with legal enactments. The peculiar process followed will be here considered.

All spirituous liquors, when the extraneous bodies from which such liquors are obtained have been removed, are identical, with this exception, that a variable amount of water is present in them; they are all more or less concentrated solutions of alcohol; thus, the alcohol from wine, rum, malt, potatoes, carrots, beets, grasses, and various other sources, is the same in quality, provided all the other solid and liquid impurities be removed. A single distillation, however, will not effect purification, and when volatile oils are present, distillation only, how often soever repeated, will not separate them, for these volatile impurities pass over during distillation; hence, the spirit procured from wines by simple distillation will have their peculiar flavour; beer, when distilled, will for the same reason yield alcohol possessing the abominable taste of the yeast; malt spirit will have the disagreeable qualities of faints from the presence of an oil of an acrid bad taste; and potato spirit the physical characteristics of fusel oil, or oil of potatoes. Thus the disagreeableness or fragrancy of distilled products is, as in the case of malt and potato spirit, due to the presence of an essential oil, derived from the source of the alcoholic liquid. The chief object of the distiller in rectifying spirit is the removal of these oily bodies in order to procure a pure alcohol, from which, by the aid of other ingredients, he can fabricate liquors imitating those more costly products which are formed naturally, such as the better varieties of brandy, gin, whisky, and all the other kinds of liquors and cordials which are in daily request as favourite beverages with the community.

The cognacs, genevas, whiskies, &c., fabricated in this country are all made from the low-wines of the malt distiller, or from the potato or carrot spirit of foreign manufacturers.

All of these spirits, as they come from the first distillation of their respective mashes, are called low-wines or *singlings*, and being charged with oils, are unfit for any use while in that state. When they are redistilled, the first portion which comes over is much purer, and contains less water than the singlings; this is called the *foreshot*. So much of this spirit as can be produced without the smell of faints, is retained as whisky, and the remaining portion is diluted and submitted to further distillation.

The strength of whisky, as sent out from the manufactory, is generally about 25 per cent. over hydrometer proof, on DICAS' scale. On a further distillation of this whisky, a spirit is obtained which marks about 46 per cent. over proof, and is about the strength of spirit of wine in general; of this, about 80 gallons are obtained from 100 gallons of ordinary whisky, of 25 per cent. over proof. A further distillation affords a liquid of spec. grav. 0·820, which is the strongest spirit that can be obtained by mere distillation.

The presence of fusel oil in alcohol may be recognized by its taste, especially after dilution with a large quantity of water; and by its smell, particularly after rubbing the alcohol between the hands, or allowing part of it to burn away. **Vögel** finds that alcohol to which nitrate of silver solution has been added, when placed in the sunshine, remains perfectly bright and clear; whereas, if it contains fusel oil, it becomes very strongly reddened.

Göbel states that the origin of any particular alcohol can be ascertained by the following means, even when no particular odour can be detected by ordinary examination. A solution of 1 part of potassium hydrate in a small quantity of water is added to 160 parts of the brandy or spirit to be examined; after agitation the whole is reduced by slow evaporation to 15 parts. An equal volume of dilute sulphuric acid is then added, and the mixture well shaken. In the case of potato spirit the vapour evolved has a very disgusting odour, and produces when inhaled spasmodic contraction of the throat, headache, and giddiness. In the case of malt spirit the odour resembles that of sour dough, and produces a similar though less powerful physiological action. Rum, arrack, brandy, have when treated in this way each their characteristic and perfectly different odour.

Caustic potassa—under the name of grey salts—or soda, is added to unite with the oil; pearl-ash—white salts—is employed with the view of combining with the water, as well as to take up the fatty or oily impurities. The alkali combines with the oil, giving a soap which remains in the still, while the spirit passes off divested of its impurities. It has been ascertained that when carbonated alkali is used, the distillate contains a sufficient amount of the salt to affect reddened litmus and turmeric; hence this method cannot always be followed.

When calcium chloride, caustic lime, sodium sulphate, potassium acetate have been employed, either for the purpose of uniting with water or oily matter in the liquors, portions of these bodies are, according to the statements of **Dubue**, invariably found in the distillate. The same authority states, that when spirit was distilled over calcined alum, the condensed liquid reddened litmus paper; but when sulphuric acid was added in small quantity to the spirit, the product which came over was found to be quite pure. Alumina, or aluminous clay, well washed and dried, was found capable of extracting small quantities of water from spirit, and no portion of it passed over into the receiver.

Charcoal is a means by which the disagreeable flavour of spirituous liquors is removed. It has been made the subject of investigation by many chemists, among whom **Löwitz** ascertained that, by distilling common malt spirit over charcoal, or by merely agitating the two together, its peculiar bad smell was removed. He performed ten experiments with one pound of common spirit for each operation, and a variable quantity of charcoal, from half a drachm to five ounces, with the following results:—

Half a drachm of charcoal scarcely altered the smell, and the liquor did not clear for six months.

One drachm of the charcoal had no better effect in removing the bad flavour and odour; but cleared it in four months.

Two drachms cleared the spirit in one month.

Four drachms removed the smell in a very sensible degree, and the spirit became clear in one month.

One ounce of the charcoal completely freed the spirit from the bad smell, and clarified it in a fortnight.

An ounce and a half cleared it in eight days; three ounces in five days; four ounces in twenty-four hours; and five ounces in two hours.

The charcoal, mixed with water and distilled, yields an additional quantity of alcohol, but very impure, because at the heat required for the distillation part of the absorbed fusel oil is likewise parted with. The charcoal is said to be the more active the softer it is. For purifying brandy **Stickel** prefers bone charcoal to wood charcoal.

Kunkel was the first chemist who made the essential oils contained in spirit the object of research. His method of rectification was to dilute largely with water and distil. The fusel oil being less volatile, passes over towards the end of the distillation, and yields, when nearly all the alcohol has passed over, a turbid distillate, because the alcohol which distils over at that stage of the process contains too much water to hold the fusel oil in solution. The head and condensing worm must be cleaned after each distillation, or otherwise the alcohol which passes over at the beginning of the following distillation will be strongly contaminated by the fusel oil deposited in them.

Wood-ashes had for a long time been almost in general use in the rectification of spirituous liquors; their beneficial effects are due to the amount of alkali they contain, which enters into combination with the small quantity of acid formed in the spirit, as well as with the oily matters.

It would appear that filtration through hydrate of lime has the effect of removing some of the essential oils from spirit; the practice had been followed in France, particularly with those who carried on an illicit trade by adding an odoriferous oil to their brandies, and then entering them at the customs as perfumes.

The fragrant principle was removed, subsequently, by diluting with water, and filtering through lime, slaked in the air, which had the effect of separating the oil, provided it had not been present in great excess.

Zeize affirms that agitation with a small quantity of hypochlorite of lime (bleaching powder) has the effect of destroying the essential oil, and that the spirit, after distillation from the lime compound, resembles brandy in flavour. To 1 part of bleaching powder, previously triturated to a paste with water, he adds about 664 parts of the spirit to be defuselized, and distils after forty-eight hours. If the quantity of bleaching powder is too small, some fusel oil escapes decomposition; if too large, other products, notably chloroform, pass over.

Milk, according to the views of M. CADET DE VAUX, has the peculiar property of removing the bad flavour from the spirit obtained from the wines of various mellow and sweet fruits. This is effected by one or two distillations, and the spirits obtained are almost identical, notwithstanding that they were procured from quite different sources.

The rectifying distiller has now only to remove the essential oils, since the improved apparatus used affords an alcohol of any strength required for ordinary purposes. The proportion of salts employed for removing the oil from the crude proof spirit of the large wash distillers, is about

4 lbs. grey salts,
4 lbs. white salts,
700 gallons plain spirits.

When the distiller infers that an unusual quantity of foul oil is present, the proportion of salt is increased, and sulphuric acid is also added in order to improve the flavour of the spirit by giving rise to an ether. The salts are dissolved in about two gallons of liquid, and the sedimentary impurities removed by filtration. The solution is then mixed with the crude spirits, and distillation commenced. If the common still be employed, great attention must be paid to the fire; for if it be not slackened when the liquid first boils, there is much risk of the still *running foul*, that is, boiling over through the neck of the still, which occurrence would of course spoil the operation; when, on the contrary, the improved stills, which have been already described, are used, no danger is to be apprehended from this evil.

In rectifying faints, 80 under proof, the following method is used:—The spirit is mixed with the proper quantity of alkali, and the stills charged; the first portions that come over are collected separately, till the spirit runs at about proof, when it is turned off into another receiver; the result of this rectification —the common still being employed—will be about 10 per cent. over proof. On rectifying a second time, the distillate at first marks 43 per cent., and is collected till it indicates 30; it is then conducted into another back until reduced to 10 per cent. over proof, and the residual portion, after this strength, is received in the faints-back. A third rectification will afford a spirit of 53 per cent. over proof, or spirit of wine. In the second rectification, only one half the quantity of salts employed in the first operation is made use of; and in the third, it is customary to add about 4 lbs. of animal charcoal, and 10 lbs. of coarse grained common salt, to every 100 gallons, to cleanse the still. When ST. MARC's stills are used 1200 gallons of proof ordinary wash spirit can be rectified in ten hours, product being 60 per cent. over proof, and stronger; a longer time is required to distil the whole contents, but the trouble of repeated distillations is dispensed with, besides, a considerable saving in labour and fuel is effected.

GENEVA.—This liquor has been long the subject of study among distillers. Many trials have been made to produce in this country a spirit equal in quality to that imported, but with very indifferent success.

The subjoined particulars were communicated to the late Dr. THOMSON, by a gentleman who resided in Holland for several years, solely for the purpose of learning the process followed in the manufacture of the Dutch hollands or geneva.

112 lbs. of barley malt, and 228 lbs. of ryemeal, are mashed with 460 gallons of water, at 162° Fahr. (72°·2 C.); after infusion has taken place, cold water is added to bring the strength to 45 lbs. per barrel, or spec. grav. 1·047, at which strength, after it has cooled to 80° Fahr. (26°·6 C.), it is run into the fermenting tun. To the contents of the fermenting back, which is about 500 gallons, half a gallon of good yeast is added; fermentation speedily sets in, the temperature rises to about 90° Fahr. (32°·2 C.), and the attenuation is complete in forty-eight hours. After attenuation of the wash, from 12 to 15 lbs. per barrel of saccharine matter remain undecomposed in the fermented liquor. The wash and grains are then introduced into the still, and the whole of the low-wines distilled over; these are subjected to a second distillation, and the distillate after rectification is the famous "geneva." A few juniper-berries and sometimes hops are added in the rectification, to impart to the spirit its peculiar flavour.

Some peculiarities may be noticed in the process followed in Holland, namely, the imperfect attenuation of the wort and the small amount of yeast employed in bringing it about. The British distillers obtain double the quantity of spirits from their worts that is produced by the Dutch distillers, if the example just given be true. It is very probable that the large amount of yeast used by British and Irish distillers, and the efforts made to effect as low an attenuation as possible, are the causes of the flavour of British gin being so inferior to Hollands. The only liquor in this country which can bear comparison with that of Holland is the illicit product. A manufactory for the production of Hollands was instituted some few years since at Maidstone, in Kent. It never became popular, and after languishing a few years ended in bankruptcy. It has never since been revived.

BRITISH GIN is, for the most part, manufactured by the rectifiers of the low-wines of the Scotch and English spirit or whisky fabricators. These processes are generally carried on in a somewhat uncouth fashion.

The still is charged with 300 gallons of liquor, and 650 gallons of spirit from a previous rectification, to which are added:—

95 lbs. German juniper berries,
95 lbs. coriander seeds,
47 lbs. crushed almond cake,
2 lbs. angelica root, and
6 lbs. liquorice powder.

The whole is well rummaged, distillation commenced, and after the worm is cleansed by the first portions drawn over into the faints-back, about 160 gallons are run into forcing-back No. 4, then turned off into back No. 3, till it runs 1 to 9, or 11 per cent. over proof, when it is turned into faints-back No. 8.

About 400 gallons are found in back No. 3. Liquor is run into back No. 4 to reduce it to 50 per cent. under proof; it is fined by throwing into it 2 lbs. of alum dissolved in boiling water, and leaving it to rest for about eight hours, after which this *low gin* is pumped into back No. 3, containing the remainder of the charge, to bring it to 22 per cent. under proof; then the whole is pumped into store casks for use.

Another standard recipe for *Cordial Gin*:—Take 700 gallons of the product of the second rectification (if the improved stills are used the product of the first distillation answers), and mix with it the following ingredients:—

70 lbs. German juniper berries,
56 lbs. coriander seeds,
5 lbs. almond cake, crushed or broken,
1½ lb. orris root, broken,
2½ lbs. angelica root, cut,
½ lb. cardamom, or, instead of this,
6 lbs. liquorice powder are sometimes added.

Force the first running of the working, or about 200 gallons, by reducing it to 50 under proof, adding three quarters of a pound of alum, boiled in 2 quarts of water. In adopting this recipe, make a double working of it with twice the quantity of the ingredients. Work in the flavouring in the first charge of rectified spirits, having in the back 2 or 3 inches of the usual charge, to make up with liquor, and prevent the bottom of the still from injury by the charring of the large amount of ingredients depositing upon it. Turn the distillate into another back, and reduce to 50 per cent. *under proof;* force with 1½ lbs. of alum and pump into fining cask; then charge with rectified spirits and work into back containing goods from preceding charge. Run down gin from store cask and make up to strength required—17 to 22 under proof.

Another recipe for the manufacture of Cordial Gin, the charge being 950 gallons, is the following:—

100 lbs. juniper berries,
70 lbs. coriander seeds,
2 lbs. orris root,
1 lb. angelica root,
2 lbs. calamus root,
½ lb. cardamom seeds.

The operations being the same as those just recounted.

For a *Fine Gin*, the distillation of which is carried on for the most part in the same manner as the above, take

960 gallons of spirit, hydrometer proof,
96 lbs. German juniper berries,
6 lbs. coriander seeds.
4 lbs. grains of paradise,
4 lbs. angelica root,
2 lbs. orris root,
2 lbs. calamus root,
2 lbs. orange peel,
80 or 90 lbs. of liquorice powder are occasionally added, to impart colour and sweetness.

Plain or *London Gin* is made in the following proportions:—

700 gallons of the second rectification,
70 lbs. German juniper berries,
70 lbs. coriander seeds,
3½ lbs. almond cake,
1½ lb. angelica cake,
6 lbs. liquorice powder.

For the manufacture of *West Country Gin* the annexed is the process:—Introduce into the still 700 gallons of the second rectification, and flavour with

14 lbs. German berries,
1½ lb. calamus root, cut, and
8 lbs. sulphuric acid.

This gin is much used in Cornwall, and particularly in the western counties of England; it is also used in making British hollands, and in that case is mixed with about 5 per cent. of fine gin, reduced to 22 under proof with liquor.

It may be observed that all these processes merely consist in flavouring rectified spirit with various aromatic substances.

For *Geneva*, charge of still being 950 gallons of second rectification, the proportions are:—

84 lbs. juniper berries,
112 lbs. coriander seeds,
6 lbs. cassia buds,
4 lbs. angelica root,
6 lbs. calamus root,
6 lbs. almond cake,
½ lb. cardamom.

Plain Geneva.—For 950 gallons of spirit of second rectification, take

84 lbs. juniper berries,
84 lbs. coriander seeds,
2 lbs. almond cake,
2 lbs. orris root,
2 lbs calamus root.

Another prescription for making Geneva—and one which is much esteemed—is the following:—Add to 950 gallons—

14 lbs. grey salts, and
4 lbs. white salts.

The rectification to be conducted with the usual care. At the second operation, add—

168 lbs. juniper berries,
74 lbs. coriander seeds,
12 lbs. almond cake,
8 lbs. grains of paradise,
8 lbs. angelica root,
1 lb. cardamom,
2 lbs. calamus root.

In making gin with a high degree of flavour, the distillate, or flavoured liquor drawn over, is very apt to turn blue on being diluted, to prevent which is very often a difficult task. In preparing such liquors it is therefore the most advantageous method to have two stills, and to divide the charge between them. To one-half the amount, the whole of the spices and flavouring matters are added, and the liquid drawn off into two backs till it runs at 11 over proof. One of the backs is reduced as low as 1 in 2, or 50 per cent. under proof, which ought always to be observed, as in making gin it should on no account exceed this strength, but may be 2 or 3 per cent. under, without being disadvantageous. About 2 to 4 lbs. of alum are dissolved in hot water, and this solution is thrown into the back with the flavoured spirit or goods, the whole briskly stirred, then pumped into a store vat, and left to fine over night; in the morning it will be clear, and is run into the back containing the second portion of the rectified spirit, without flavouring, and diluted to 22 or 17 per cent. under proof.

In making gin of a less flavour, or where two stills cannot be employed, it is necessary to have a forcing-back to fine. To this forcing-back a small cask is attached, to enable the operator to pump off the low gin to the portion of strong in the back. The process followed in order to prevent the *blueing* is to flavour and charge the still, and to run off into the forcing-back, till it is ascertained at the worm end that the spirit will not change colour on being diluted with water; when this happens, it is turned off into the working-back to the usual strength. The gin is then reduced in the forcing-back to 50 per cent. under proof, and the aluminous solution poured in; on the following day, when the liquor has clarified, it is pumped to the making vat to the remainder of the charge, and brought down to the strength required. If too weak, it may be raised by adding the best spirit of wine in the required quantity.

In France, an exceedingly fine gin is produced by fermenting a portion of juniper berries bruised with 4 parts of barley meal, or ground malt, proceeding throughout the succeeding part of the operation in the same way as when making grain spirit.

Another method practised is the following:—Boil during half an hour 2 gallons of bruised juniper berries in 4 gallons of water; put this into a barrel capable of containing 6 gallons; add to it at first 4 pounds of rye bread that has been dried and reduced to powder, then some aromatic, according to the fancy of the manufacturer, and 2 lbs. of brown sugar. At the end of a month the liquor is converted into an agreeable wine, which, when distilled, affords a spirit much esteemed, and commanding a high price.

Having given the several mixtures used by the rectifiers in preparing their gins, a notice is given below of each substance mentioned, with a description of the oil derived from it, and its properties.

Cardamom.—The oil obtained from this seed is colourless, of an agreeable odour, and strong aromatic burning taste; the seeds are used as a condiment and also in medicine; they are stimulant, tonic, stomachic, and carminative, and yield nearly 5 per cent. of essential oil.

Grains of Paradise.—The volatile oil has a light yellow colour, a camphor-like smell, and a hot, penetrating taste; the seeds are esteemed in Africa as the most wholesome of spices, and are generally used by the natives to season their food; they are also used for medicinal and other purposes, as stomachic and cordial stimulants. Gins possessing a very peppery taste acquire it from grains of paradise.

Almond Cake.—This is the residual cake of bitter almonds, after expressing the fixed oil. When distilled it affords a volatile oil, which has a golden yellow colour, an agreeable odour, and an acrid bitter taste. Substances or liquids flavoured with bitter almonds may act injuriously, owing to the presence of hydrocyanic acid.

Angelica Root.—This root grows most abundantly in northern Europe; its taste is at first sweet, then hot, aromatic, and bitter.

Calamus Root.—The taste of this root is due to the oil, which is sharp and sweetish; the yield of oil is about $\frac{1}{60}$th per cent. It is obtained by distilling with water, and is used for flavouring aromatic vinegar.

Orange Peel.—The peel of the orange yields the oil proper, which has the strong odour of the rind.

Lemon Peel.—The oil is obtained both by expression and distillation. It is chiefly imported from Portugal, Italy, and the south of France. Pure lemon oil is very fluid, of an agreeable odour, and colourless. Its taste is pleasant but pungent, and it is, therefore, often used in culinary purposes as a substitute for the peel; the flavour, however, which it imparts, frequently savours of turpentine, and is never so agreeable as that communicated by the fresh rind of the fruit. Oil of lemon and oil of turpentine are isomeric.

Juniper Berries.—What the distiller prizes in this berry is its volatile essence, which is an oily liquid, isomeric with the preceding and with oil of turpentine; their smell is also very similar, hence the origin of the supposition that London gin is sometimes mixed with the latter. Oil of juniper is the most powerful of all diuretics. It promotes perspiration and relieves flatulency; consequently, gin is recommended in many diseases of the urinary organs.

Coriander.—The seeds have a strong smell, and medicinally are considered as stomachic and carminative; they are used in sweatmeats, in certain stomachic liqueurs, and in some countries in cooking. They contain about half a per cent. of volatile oil, to which they owe their fragrancy, and on this account the seeds are used in rectifying operations.

Orris Root is the root of *Iris Florentina*, a white flowering species of iris found in the South of Europe. It has an agreeable odour resembling violets, and is used in perfumed powders.

Liquorice.—A plant of the genus Glycyrrhiza. The root abounds with a sweet juice, much used in demulcent compositions.

Cassia.—This plant furnishes buds which consist of the calyx surrounding and nearly encircling the young ovary. They bear some resemblance to a clove, but are smaller, and when fresh have a rich cinnamon flavour. They are used for the same purposes as cinnamon and cloves. The bark and oil are powerful stimulants. Oils of cassia and cinnamon on exposure to the air rapidly absorb oxygen, yielding a considerable quantity of cinnamic acid.

Most of the roots or seeds have, so far as their oils or essences are concerned, very analogous properties and since their virtue in distillation with the spirit is to communicate their oily or fragrant principle, it would be better to add a few drops of each of the oils at once to the pure spirit, to procure the desired liquor, and by this means obviate the necessity of distilling, and the risk of injury to the stills by the mixtures mentioned, which appear to have no atomic rule for their basis.

Brandy.—This liquor is generally obtained from the high-coloured, white, or pale-red wines of the south of Europe, but is often manufactured from inferior articles, such as the refuse wine and the marcs of the wine press.

Distillation of the wines is the only thing necessary to procure this spirit; hence, the richer the wine in alcohol, the greater will be the yield of brandy. A simple test with an alcoholometer will determine the value of the wine as to the yield of brandy; but many other circumstances, independent of the manufacture, enhance the quality of the product.

Thus, the white wines do not always afford more alcohol than the red, though the spirit from the former is of a much finer quality, the reason being that they contain more of the essential oil of the grapes. It is also a singular fact, that those wines which carry with them a certain taste of the soil, communicate it to the brandy derived from them by distillation; thus, the wines of Selluel, in Dauphiné, give a brandy which has the flavour and the taste of Florentine iris; those of St. Pierre, in Vivarais, give a spirit which smells of the violet, and so of many other varieties.

Wines from the countries nearest the Mediterranean furnish the largest proportion of brandy. The wines from the south of France yield one-fourth of brandy, some even one-third, while in the north of France the amount is only about one-eighth.

The better qualities of brandy are invariably distilled from white wines; first, because a greater yield of brandy, and of a better quality is obtained; and secondly, because those wines fine more quickly, and can be distilled into brandy sooner than the red wines.

The principal stills employed on the Continent are those of Champonnois, Derosne, St. Marc, and Laugier, in France; of Pistorius, and various modifications of his apparatus, in Germany. With these stills, the spirit comes over of any requisite strength, up to the strongest spirit of wine; but if the ordinary still is employed, the receiver is changed when the vapour arising from the boiler ignites but feebly, and the *eau-de-vie-seconde*, or *repasse*, is collected by itself, till the whole of the alcohol in the wine has been exhausted. The liquid remaining in the still is called *vinasse*.

The *campaign*, or distilling season, in France, is from the beginning of October to the end of May.

The following is an average of the yield of brandy which some of the wines afford by distillation:—

1000 litres of wine of St. Gilles, in the environs of Montpellier, afford of 3/6 brandy,....	150 litres.
" " of good wine of calcareous soils,......	140 "
" " of wines of fertile soils near Montpellier,	100 "
" " of wines of soils producing much grapes,	100 "

Payen gives the following table of the proportions by volume of pure alcohol contained in 100 parts of various kinds of wine:—

Port and Madeira,... ..	20	Bordeaux claret,.......	13
Xeres, Lacryma Christi,	17	Barsac, white,........ ...	13·7
Old Madeira, ...	16	Poundensac, red, ...	13·7
Jurançon, white,......	15·2	Blaye,.................	10·2
" red,.........	13·7	Libourne,....	9·8
Malaga,..............	15·0	Saint Emilion,.........	9·1
Frontignan,............	11·8	La Réole, ...	8·5
Vauvert, ...	13·3	Cubzac, ...	8·7
Hermitage, white,......	15·5	Giscours,..............	9·4
Sauterne,.......	15	Laroze-kirwan,....	6·3
Beaune,..............	13·5	Cantenac,..............	9·2
Volnay,...............	14·7	Volnay,................	11
Dijon,................	13·0	Mâcon,................	10
Chambertin,.	12·4	Champagne,...........	11·6
Château Lafitte,........	8·7	Saumur, ...	9·9
Château Margaux,.......	8·7	Tokay,................	9·1
Château Latour,........	9·3	Rhine, ...	11·9
Saint Estèphe,.........	9·7	Chatillon,.............	7·5

Brandy, as sold in France, is generally of two degrees of gravity; these strengths are thus designated—*à preuve de Holland*, and *à preuve d'huile;* the former varies from 18° to 20° of Beaumé. The stronger liquids are valued according to the quantity of *eau de vie*, or brandy *à preuve de Holland*, that a given quantity will furnish on the addition of the proper proportion of water. These strengths are usually twelve, namely, *five-six*, *four-five*, *three-four*, *two-three*, *three-five*, *four-seven*, *five-nine*, *six-eleven*, *three-six*, *three-seven*, *three-eight*, and *three-nine*, but the last is rarely made. The meaning of these strengths is understood in the following sense:—If a spirit be five-six, five parts of the spirit will give a liquor *à preuve de Holland*, when added to six measures of water; if three-six, three measures when added to six of water will yield a spirit of the same standard, and so of the remainder.

The spirit five-six strength is of a specific gravity 0·9237, or 22° Beaumé; but all the other strengths are subject to variation, on account of the uncertainty of the strength *à preuve de Holland*, as before shown. Wines, when distilled carefully from a clean apparatus, yield a distillate which is nearly colourless, and when it is wished to retain it in this state, vessels of glass or stoneware are employed. After being put in casks and left in them, the clear liquor acquires a little colour by extracting the soluble matters of the wood; the flavour, however, is not materially affected if the casks are old; when new casks are used, the tannic acid of the wood, which is generally oak, communicates a deep colour and astringency of taste which is quite foreign to the brandy.

The brandy from different localities, and even from a different variety of grape grown on the same place, possesses, as already remarked, an aroma characteristic of the wine whence it is obtained, and which is readily perceptible to those well versed in the trade. An experienced taster will readily distinguish the brandies of Languedoc, Bordeaux, Armagnac, Cognac, Aunis, Rochelle, Orleans, Barcelona, Naples, &c.; further, he can say from what species of fruit it is derived; and he will also discern minute shades of difference in the qualities of various brandies from the same source. Real cognac is obtained from the distillation of the choicest wines, every regard being paid to the proper degree of cleanliness which should be observed in the various utensils through which it has to pass. In the improved forms of still a very superior article is obtained from inferior wines, but the large proportion of essential oils in such wines spoils the flavour of the brandy.

An inferior variety of brandy, or *eau de vie de Marcs*, is obtained by distilling the dark-red wines of Portugal, Spain, and other wine-growing countries, the lees deposited by wines when kept, the marcs or refuse of the grapes from the vine-press, the scrapings of wine casks, &c.

Distillation is with these inferior materials carried on in the ordinary way, but as the flavour is less regarded, the spirit is drawn off rapidly, and at a high temperature. The marcs from the vine-press are prepared for the purpose of distillation by breaking the cakes up into pieces, and throwing them into water. A temperature of 70° to 80° Fahr. (21°·1 to 26°·6 C.) is kept up, and in the course of a short time fermentation sets in; when this has ceased, the solution is racked off and distilled. The first distillate has a whitish colour, and is called *blanquette*, but this on redistillation yields a spirit of 22° or 24° Beaumé. One pound of brandy is produced from 85 to 90 lbs. of cake.

The fermentation of the cakes is sometimes effected in large pits, where they are covered with earth. The progress of fermentation is known by thrusting the hand into the heap. When the temperature decreases, the fermentation is said to be finished; the contents are then taken out, water in proper quantity added, and distilled. By this process 100 lbs. of marcs yield 1 lb. of brandy.

When such liquors are distilled, the sedimentary matter subsides, and is apt to carbonize on the bottom of the copper still; when it does so it communicates a smoky flavour to the distilled liquor, in addition to a hot fiery taste proceeding from the fusel oil of the skin of the fruit. AUBERGIER has proved that a few drops of fusel oil are sufficient to taint a pipe of 133 gallons of pure spirit.

In some distilleries the carbonization is hindered by keeping the contents of the still in motion by agitators. Other manufacturers insert into the body of the still a basket to retain the sediment accompanying the fermented liquor, thus preventing its contact with the lower part of the still. M. REBOUL's process is to inject steam into the still by means of a coil of piping. The stills in this case are large wooden boxes, to which worms are adapted in the usual way, and the whole of the alcohol is driven over by steam heat. M. CURANDAU's apparatus consists of a still, the neck of which is as wide as the body, and 3 feet in height; brackets are placed at the distance of 9 inches in the neck of the still, which support several partitions; these are provided with short pipes, pierced with holes, to allow the vapours to circulate freely from the body of the still. The neck being affixed, and the first partition introduced, wine lees are poured in, which are filtered by the perforated partition; then the second, and a further quantity of lees, and so on till all the partitions are inserted, and the lees are about 6 inches thick on each. If the liquid drained from the marcs or lees be not sufficient to fill the still, water is added to make up the proper quantity. Heat is then applied, and the steam, as it passes off, expels the last portions of spirit from the solid particles retained by the partitions in the neck of the still.

Most of the inferior kinds of brandy contain an acid which partly unites with the oil from the grapes, rendering the taste of the spirit unpleasant; agitation with a little quicklime not only removes the acid, but also the oil in a great degree. The matter left in the still when dried and burned yields an alkaline carbonate, which is disposed of for dyeing operations.

Spirits of this class are used by the lower order of people in France, and on account of their hot fiery taste are often preferred in England and other northern countries to a more genial produce. Cognac and Armagnac brandies contain about half their weight of water, and owe their fragrancy to the aroma, indigenous to the wine, being less disguised by the fusel oil.

Ethyl pelargonate ($C_2H_5,C_9H_{17}O_2$), the ether of pelargonic acid ($C_9H_{18}O_2$), originally described as œnanthic ether, is a liquid possessing a most powerful and intoxicating odour. The aroma of wine is in great measure due to the formation of this ether during fermentation. When wines or marcs containing this ether are distilled, an oily liquid passes over towards the close of the operation, which consists in great measure of crude ethyl pelargonate, and imparts the aromatic odour which cognac and other liquors possess. PELOUZE first proved this odorous principle of wine to be a compound ether. MULDER detected the same in the oil of grain-spirit and in other fermented liquors, and it is from this ether that quinces derive their distinctive perfume.

The effect of heat on several of the substances contained in wines merits the attention of the distiller. A temperature slightly too high sometimes destroys a whole distillate, as empyreumatic and other products are generated.

When, to save expense in carriage, the spirit is rectified to a much higher degree than the above, the dealer, on receiving it at Paris, reduces it to the market proof strength by the addition of water or of a little fragrant weak brandy; but the brandy produced in this manner is not equal to that derived from the distillation of Cognac wine at an incipient heat. This may be readily proved by submitting to distillation, with every precaution, brandy of a superior quality; if the resulting spirit be then brought down to the ordinary strength with water, it will be plainly perceived that the liquid has been considerably deteriorated by the operation. Genuine French brandy evinces a red reaction with litmus paper, owing to a minute portion of acid; and when kept for a considerable period in casks, it acquires an astringency which impairs its quality.

The brandy sold in England is, for the most part, artificial—the fabrication of the rectifying distiller. The following is one of the recipes for the purpose:

—Dilute the pure alcohol to the proof pitch, and add to every 100 pounds weight of it from half a pound to a pound of argol—crude winestone—dissolved in water, some bruised French plums, and a quart of good cognac. Distil this mixture over a gentle fire, in an alembic provided with an agitator. The addition of brandy and argol introduces œnanthic ether, and if a little acetic ether be added to the distillate, the liquor acquires the peculiar taste of genuine cognac brandy; colour with burned sugar, if necessary, and add a little tannic acid to impart astringency.

The process followed by the rectifier is somewhat different, as will be seen from the subsequent few examples, which are transcribed from the private work-book of a very extensive rectifying distiller. The source is generally the common low-wines of the grain distillers, which are rectified in the usual way by distillation with caustic salts, as has been already described.

To every 500 gallons of this spirit, about 25 gallons of the best French wine-vinegar are added, and the whole well rummaged in the mixing-back; the mixture is then pumped into the still, and a further quantity of a weaker spirit run into the back, in order to clear it of the last traces of vinegar; this liquor is also pumped into the still to make up. From 56 to 60 lbs. of coarse-grained common salt are now mixed with the liquid in the still, together with from 8 to 10 lbs. of concentrated sulphuric acid, keeping the whole in brisk motion during the addition of the latter, to protect the still from the action of the acid. The fire is then lighted, and the still brought down and worked till the spirit shows a strength of 14 over proof, or one-to-seven. It is customary to turn off into the faints-back at a lower degree of strength, and collect the remaining quantity of faints; in such a case, however, the quality of the spirit is not so good. From every 500 gallons of the charging, 500 to 510 gallons of spirit, marking 42 per cent. over proof, are obtained. This is mixed with from 400 to 450 gallons of liquor, and pumped into the British brandy store-vat: 20 to 25 gallons of *fruit tincture*, 15 gallons of brandy flavour, and 8 to 10 gallons of good colouring are then introduced into the piece, the whole well rummaged, and left to fine. It is considered an improvement to fine with skimmed milk. Some distillers prefer to introduce distilled vinegar in the proportion of 15 to 20 gallons to 1000 gallons of the compounded liquor in the store cask, instead of adding it previous to distillation, as before mentioned.

Another recipe, which is followed for the most part in the distillery from which these details were obtained, using a multiple of the number, is next given.

Three hundred gallons of proof spirit are distilled with the proper addition of caustic salts, taking all the precautions mentioned in the preceding, under Rectification of Spirits, and the distillate is received into the spirit-back till it runs at ten over proof. The remaining spirit is turned into the faints-back, and is then made up with 450 gallons of spirit, 22 under proof, 20 gallons of *prune tincture*, 20 gallons of distilled vinegar, and 8 gallons of good colouring matter.

When flavoured faints are cleansed, charcoal is employed in the rectification with sulphuric acid.

Raspberry Brandy.—In manufacturing raspberry brandy, the subjoined is the process:—For 1000 gallons of the brandy, take

460 gallons of raspberry tincture,
115 gallons of cherry tincture,
240 gallons of sweets,
96 gallons of British brandy, 22 U.P.
89 gallons of liquor;

rummage the whole well, and force or fine with isinglass.

Cherry Brandy.—To make 1000 gallons, take

575 gallons of cherry tincture,
253 gallons of sweets,
92 gallons of British brandy, 22 U.P., and
80 gallons of liquor;

the whole to be well agitated, and fined with isinglass.

Raspberry tincture is made as follows:—Take a brandy puncheon with head out, and screen over the cock; put in 50 gallons of clean rectified spirit of 22 under proof, then fill the cask with raspberries. In three weeks or a month draw off the whole of the tincture into a clean cask, and add to the fruit a second time 25 gallons of spirit of 22 under proof; let this remain upon the raspberries a month longer, and then draw this off, and add it to the first tincture; after which the whole of the tincture remaining in the fruit is to be pressed out and added to that already obtained. The cake is then broken up and steeped in a rum puncheon with the head out, 40 gallons of spirits are added, the whole contents briskly agitated from time to time for three or four days, and pressed well after drawing off the solution. This liquor is employed in making up the raspberry brandy instead of water.

Cherry tincture is made in the same manner as the raspberry, by substituting the one fruit for the other.

For prune tincture cover 56 lbs. of prunes, thoroughly broken up, with 20 gallons of clean spirit of wine, and after being allowed to stand for eight or ten days, rack off; the refuse fruit is washed twice with liquor, and the residue is then thrown away.

Many rectifiers prepare a brandy flavour as follows:—To 100 gallons spirit—clean faints, 54 over proof—add

100 gallons of good strong vinegar,
4 gallons of spirit of nitre,

in a back, and mix the whole thoroughly, cover closely, and the next day run it into the still with

8 lbs. of nitric acid,
10 lbs. of almond cake,
5 lbs. of orris root, and
2 lbs. of lemon peel;

work the still slowly, and turn off at proof strength

In making up brandy, 10 per cent. of the above flavouring is employed, but more or less may be used to suit the taste of the consumer.

In Switzerland brandy is distilled from the refuse of the grapes after the juice is pressed out. Large casks are filled with the skins, which are squeezed as compactly as possible, and covered closely to prevent the access of air; fermentation usually commences in about three days, and when it has finished, which requires a considerable time, the mass is deemed ready for the still. When the distillation is to take place, the fermented mass is mixed with a due proportion of water, to reduce it to a proper consistence for the action of the fire, which is moderately applied to prevent empyreuma. It is said that a vessel containing 32 cubic feet of this material will yield 10 gallons of pure brandy.

RUM.—Molasses is the name given to the syrup which remains after the crystallization of sugar; it is, in fact, the mother liquor of sugar. This syrup, diluted with a sufficient quantity of water, undergoes the vinous fermentation, and by distillation yields a spirit called in the colonies *rum*, or *taffia;* the name given to it in the Isle of France and Madagascar is *guildive.* This spirit is of excellent quality when prepared with proper precaution, and particularly relished when it is very old. The best rum is made solely from molasses. An inferior quality is made from the debris of the sugar-cane, which has always a sharp disagreeable acid flavour, and frequently acquires an empyreuma, on which account it is given to the negroes who work in the sugar-houses, and is consequently called *negro rum.*

In the fermented liquor from which the rum is distilled, acetic acid sometimes exists in large quantities, accompanying the ardent spirit without forming ether; but in distillation a certain quantity of acetic ether is formed, which, from its extreme volatility, rises in the first process of distillation, giving to the vapour a most disagreeable taste and smell; hence the colonial saying, that the rum becomes *too hot* if rectified like European spirits. The cause of this is easily explained: the rectified spirit only forms a part of the charge of the still, and contains, nevertheless, *all* the acetic ether.

Skilful distillers, who pride themselves on making these strong spirits most agreeable to the taste, take great care to remove all kinds of vegetable matter or refuse incapable of producing vinous fermentation, as such substances have a tendency to putrefy, and the putrescent matter retards the action, and gives a savour which is communicated to the distilled spirit.

The Chinese, who prepare the famous arrack of Batavia, which is the best of all rums, take much care in rectifying it, mixing with it during distillation a composition called *ragie*, in which is cinnamon and anise-seed, in such proportion as not to be perceived either by smell or taste, being only sufficient to do away with the otherwise nauseous odour of the liquor. The Madagascars throw in leaves of trefoil. The Asiatics mix with it the bark of a kind of thorny acacia, called *pattay.* Some persons put into the still with the grape the leaves of a tree named *attier* in the East Indies, and *pommier cannelle* at St. Domingo—*ænona squammosa*—which have a light agreeable odour. Others have tried with success the mixture of peach leaves. All these substances impart to strong liquors a pleasant bouquet and taste, and are used to disguise the smell of the spirit, and to give it unctuousness.

The chief seats of the distillation of this spirit are the East and West Indies, America, and France. It is strange that the Chinese, who produce so much sugar annually, and who, consequently, might manufacture large quantities of rum from molasses, have not hitherto attempted to distil this article.

In the West Indies the liquor of the sugar-cane runs warm from the coppers through a trough to a receiver prepared for that purpose. It is then skimmed, and the skimmings, with some of the liquor itself, are pumped into a cistern containing from 300 to 800 gallons, when the fluid is mixed with water and molasses in the proportion of 25 gallons to 100. When this mixture is sufficiently blended together in the vats, which in some plantations amount to thirty, it is covered over with boards or mats of plantain leaves and allowed to ferment for three or four days, or longer, should there be a want of yeast or other ferment to make it work, which often occurs at the commencement of the season. When reduced to a due degree of acidity, which is ascertained by the subsidence of the fermentation, it is run into a still proportioned to the vat, and wrought off as low-wines, in which state it is put into the still again. The first run, or discharge, after it is thus returned to the still, is taken off for *high*-wines, as they are termed, or strong rum, in the proportion of 25 to 300 gallons, the strength of which, when tried by a glass-bead instrument, is from 18° to 22°. The second run of the still, which is drawn off in cans, and carried by negroes to another vessel, is of a strength from 23° to 26°. From these two runnings of the still the rum exported from the colony of Demerara is made up. Any deficiency in the strength of the second distillation is compensated by an addition from the first, which is always stronger than that exported, and of too ardent a nature to be used by itself, 25° being colony proof.

In the Windward Islands, one-third of the skimmings is mixed with one-third of the lees and one-third of water. When these begin to ferment, which they usually do in twenty-four hours, the first mixture of molasses is made in the proportion of 6 gallons for every 100 gallons of the fermenting liquor, and a day or two afterwards an additional quantity of molasses is added. The fermentation is tempered by the addition of cold or warm water. *Dunder* is the lees or feculencies of former distillations, and serves all the purposes of yeast in the fermentation. It is derived from a Spanish word, *redunder*, the same as *redundans* in Latin, and is well known among the planters in the West Indies. The attenuating properties of this ferment are such, that the materials with which it is mixed are said to yield a much greater proportion of spirit than could be obtained if they were fermented without it; it serves the same purpose as jalap mixed with molasses, which has been sometimes employed in Great Britain for cutting down the frothy head at the close of fermentation; and it is usually preserved from one year to another for this purpose, in such large quantities as to fill most of the backs or fermenting tuns. Dunder soon becomes covered with so thick a film as to exclude the air, and the sediment leaves the intermediate fluid pure, of a bright amber colour, which, when carefully drawn off, is employed as already described, in proportions suited to the nature of the fermentation.

Dunder fulfils two important offices in the distillation of rum. In the first place, the large quantity of acetic acid contained in it, and formed at the expense of alcohol during fermentation of the wash, serves to decompose the calcium saccharate contained in most West India molasses in considerable quantities. It is for this reason that dunder increases the yield of the rum. Saccharate of lime does not ferment, and when present in considerable quantity actually opposes the fermentation of the wash; so that without dunder fermentation would proceed so sluggishly, that most of the alcohol would be converted into vinegar. This occurrence might be avoided by adding the diluted molasses containing saccharate of lime to its own bulk of strongly fermenting wash. The carbonic acid of the fermenting liquor would then perform the office of the acetic acid of the dunder, by precipitating the lime as carbonate of lime and liberating the sugar. The idea that dunder is connected with the fine flavour of rum, Horsfield disproved by two experiments. In one trial molasses—from which all the lime was precipitated by sulphurous acid—and water only were used. The resulting rum was a very fine-flavoured spirit, and the yield was perceptibly greater than from molasses not thus treated, though from similar cane. Another trial was made by partially filling the rectifying vessels or retorts, as they are called in Jamaica—they are like the wash-heater, as prepared B, Fig. 45, and connected with the still in the same manner—with dunder, with a view to increase the flavour of the rum, as might be expected if the flavour proceeded from that source. The rum, however, thus obtained had the disagreeable taste of dunder, and was totally different from that of *Old Jamaica*. The flavour of rum appears to depend entirely on the presence of a fusel-oil, the formation of which is immediately dependent on the proportion of the surface of the wash exposed to the air during fermentation, to its entire volume. It is well known that two contiguous sugar plantations will produce very different qualities of rum, though operating in the same identical way. But it has been observed that in such cases the size and the exposed surface of their fermenting vats were different, or if not, the stills were of different capacity. The protracted boiling of the wash in very large and deep stills, injures the flavour by increasing the empyreumatic products. From the above observation it would follow, that the origin of the genuine flavour is intimately connected with the more or less complete oxidation of the molasses ferment induced by the greater or smaller surface of the wash—compared with the bulk—exposed to the air. Large cubical cisterns, holding 1000 and more gallons, yield an inferior rum, as compared with smaller vats having a larger exposed surface. Similar observations made by LIEBIG with regard to Rhenish wine appear to confirm this opinion.

The second office fulfilled by dunder—an office of some importance for the more rapid development of fermentation—is by its richness in ferment. The colonial distiller does not employ any yeast for inducing fermentation of his wash; he is consequently obliged to work upon more dilute solutions of molasses and skimmings, collectively called *sweets*, than are used by his continental competitors. Any, even the slightest source of ferment, must therefore be welcome for his purpose. Dunder is such a source. Ferments, it is well known, are destroyed by boiling-heat of water, and recent dunder is in that respect perfectly inert; but by exposure to air in shallow tanks an oxidation and regeneration of the *killed* ferment takes place, and it is to this circumstance that a part of the favourable action of dunder must be ascribed.

Rapid fermentation of the wash may be obtained without the assistance of dunder, by converting the cane-sugar contained in molasses into grape-sugar, by treatment with a small quantity of acid, which is subsequently neutralized. Less ferment is required for converting grape-sugar into alcohol than cane-sugar. Some plantations manufacture superior rum though their sugar is nearly as dark as coal-tar. Molasses from such sugar contain chiefly grape-sugar.

Much attention should be paid to proper adjustment of the amount of water employed in the preparation of the liquor. Before commencing, the various boilers and vats are thoroughly washed and freed from saline matter, by hot or cold water.

In the beginning of the distilling season, more sugar is employed than is afterwards found requisite; the reason of this is, that the distiller has no good lees and very little molasses to add to the mass; besides, the scum or froth from the sugar is not so rich from the first boiling of the season as in the months of March, April, and May, which is the most favourable time. The following proportions succeed well at starting:—For every 136 gallons content of the vat, pour in 61 gallons of scum, 7 of molasses, and 68 of water When the lees and dunder are good, equal quantities of skimmings, lees, and water are employed, and for 100 gallons of this mixture, 10 of molasses are added. Should the pressing-mill be not in operation, and skimmings cannot be obtained, it is found advantageous to employ equal parts of lees and water, and with every 136 gallons of the compound 27 of molasses are mixed. With mixtures such as these, the distiller can obtain from 10 to 15 per cent. of rum and other products; but this quantity depends very much upon the quality of the ingredients operated upon, as also upon the state of the weather and time of distillation; hence, an intelligent distiller varies the proportion of the bodies submitted to fermentation.

Rum differs from what is termed sugar spirit, for it contains more of the natural aroma, or essential oil of the sugar-cane. When the West India distillers have enough of matter, they mix water with it, and allow it to ferment in the ordinary way; the fermentation proceeds slowly at first, on account of the scarcity of the yeast, but as soon as sufficient ferment has been produced, it operates quickly on the whole mass till the attenuation is finished. This liquid is then distilled, and produces a spirit of great strength, nearly equal to alcohol, which they name *double-distilled rum*, or *double rum*. The spirit is more easily concentrated if much liquid be submitted to distillation, but in the course of this operation it yields such a large amount of oily matter, that it cannot be used for a considerable time. For preserving the rum, either for exportation or other purposes, it is found useful to make the double rum so as to form alcohol, or ardent spirit. In this state it occupies only half the volume of the ordinary liquid, and can be diluted with water to suit the taste of the consumer, or to the common strength.

The still for the most part used in those islands, and by which a great saving of fuel is effected, is represented in the annexed engraving, Fig. 41. It consists of two distinct parts: A is the boiler, and B the vessel which contains the fermented wash, to be heated previous to its introduction into the still. The boiler and preparer are placed in such relative positions that the heat of the fire, after doing the required service to A, passes under the vessel, B, and thus communicates heat to the liquid. The plan of the construction is seen in Fig. 42, where the arrows show the course of the flue under both these vessels. The waste heat enters the chimney by a damper-opening at the back. *a* is the passage from the fire under the preparer; *b*, a lid screwed firmly on the vessel, B, which resists the pressure of any vapour generated in this vessel; *c*, a safety valve; *j*, the chimney; *h*, the fire-door; K, the tube which carries off the vapours to the condenser attached to the alembic, which communicates by a pipe not shown, with the preparer, B.

When operations commence, the preparer is filled with the fermented liquor, and likewise the still, to a proper height; the fire is then lighted, and the liquid in the alembic very soon boils, and that contained in the preparer at the same time acquires a temperature approaching ebullition, by the waste heat communicated from the flue beneath this vessel. As soon as the matter in the boiler is exhausted of alcohol, the fire is slackened, the residuary liquid drawn off by the discharge-cock, and the boiler replenished by opening the stopcock of the pipe which connects the alembic and preparer. The fire is again urged, the vessel, B, refilled with fresh liquor, and the distillation proceeded with, as in the previous instance.

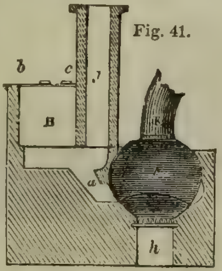


Fig. 41.

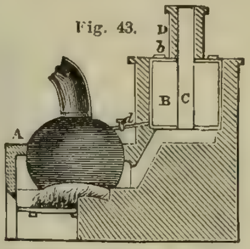


Fig. 43.

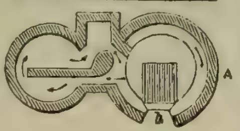


Fig. 42.

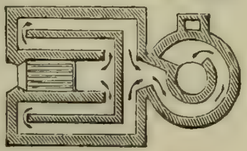


Fig. 44.

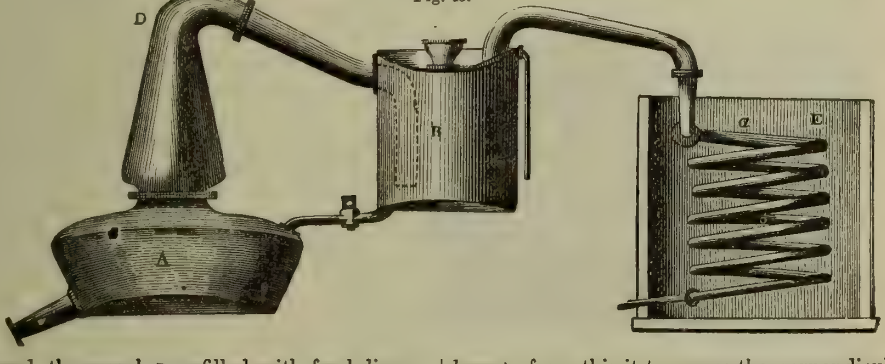


Fig. 45.

Another form of apparatus used by the West Indians is seen in the engravings, Figs. 43 and 44. This still and preparer differ only slightly from the preceding. A is the boiler, B the preparer; and the mode of communicating heat to the latter is seen in the plan, Fig. 44, where the course of the heat from the fire is indicated by the arrows, till it enters the circular space of brickwork called the *bonnet;* from this it traverses the perpendicular pipe, C, passing through the middle of the preparer, and thence into the chimney, D. *b* is the lid of the preparer, and *d* a pipe that connects this vessel with the boiler. This arrangement has an advantage over the common furnace, on account of the larger amount of heat it communicates to the boiler flue, and any extra heat is made useful in heating the liquor in the vessel, B.

The annexed form of still, Fig. 45, is also frequently employed in the West Indies. It consists of the boiler, A, with an elongated conical head, D; the preparer, B, into which the wash is introduced by the funnel-basin, C; and the condenser, E, where the spirituous vapour is liquefied in passing through the numerous convolutions of the worm, *a*. The peculiarity of this form of still consists in the communication of the pipe, D, with the preparer, B, by which means the vapour from A is partially condensed in the preparer. The vapour is carried to within a few inches of the bottom of the vessel, B, as shown in the figure by the dotted continuation of D; the liquor in B is heated by the steam condensed in it, as well as by the alcohol which passes through it uncondensed to the worm, *a*. By this arrangement fuel is economized, and a strong spirit is procured at one distillation.

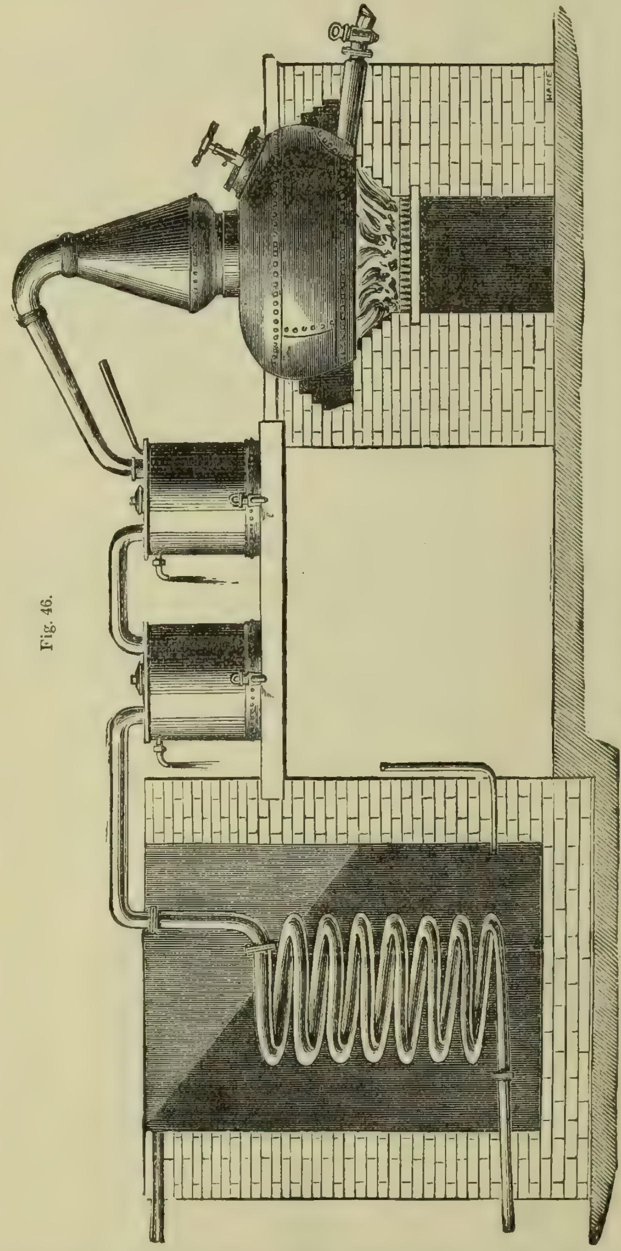


Fig. 46.

Fig. 46 shows PONTIFEX'S still, now generally used for rum in the West Indies and elsewhere. The still is of copper, with a discharge pipe and cock, and a manhole for cleaning, &c. The still is shown set in brickwork and heated by fire, but sometimes it is fitted with an outer casing or jacket of iron, and steam passed between the still and the jacket—the heat necessary for distillation being thus obtained without the direct action of fire. On the top of the still is a conical head of copper, with a neck and arm leading to the next part of the apparatus, which consists of two copper cylindrical vessels, usually called "retorts" by the distiller. Each retort is fitted with a discharge cock and manhole, and in the best construction the top or cover is a few inches below the top of the sides, leaving what is termed a "water chamber." To the retort next the still a small pipe is attached, through which cold water is run to the water chamber, and discharged on the other side, as shown. The same thing is also done with the second retort. The use of these water chambers will presently be seen. The arm pipe that enters the top of the first retort is continued to within a few inches of the bottom. The pipe from the first to second retort is taken from the top of the first, but is continued down nearly to the bottom of the second, in the same manner as the arm pipe in the first retort.

These retorts are on the same principle as WOULFE's bottles (Fig. 7). A pipe is taken from the top of the second retort, and leads to an ordinary condensing worm made of copper or pewter, placed in a tank, frequently made of bricks, through which cold water is kept flowing. The lower end of the worm passes through the tank for discharging the spirit.

The following is a practical description of the method of rum distilling, as conducted in the West Indies, with a still like that just described:—Wash, from which rum is distilled, is composed of sugar skimmings (4 parts), lees of still (5 parts), and molasses (1 part) (the total quantity being the same as the charging capacity of the still to be used), the materials being mixed in a vessel called the "mixing cistern."

The lees of still is a term for the residue left in the still after distillation; and when commencing, of course, no lees are on hand, and then water should be substituted. The wash is pumped into the fermenting vat, and there fermented; the vats are skimmed twice a day during fermentation, which usually occupies fully a week, and when that is completed the fermented wash is ready for the still. The still is charged up to the manhole, and a steady fire kept up. In each retort a quantity of low-wines is put, sufficient to cover the end of the descending arm pipe in first retort, and the pipe from first retort in the second one. In place of low-wines, wash may be used. When, from the heat, the vapour rises from the wash in the still, it passes up the head and down the arm pipe into the first retort: there, the hot vapour coming in contact with the low-wines, a second distillation takes place, and vapour rises to the top of the retort to escape by the pipe leading to the second retort; but the cold water running over the top in the water chamber condenses the weakest portions of the vapour, which fall into the bottom of the retort as low-wines, the stronger vapour only passing into the second retort, where a similar process takes place. The vapour rising from the second retort is freed of its aqueous parts and impurities, and passes into the worm, where it is condensed and discharged as spirit. The spirit thus obtained is much stronger and better than that produced by a still and worm only, without retorts.

The "faints," or low-wines left in the retort after distillation, are drawn off and kept in a cistern until there is enough to make a charge for the still, and then that is worked off in the same manner as fermented wash. Fresh low-wines are used in the retorts at each distillation.

About five hours are required to work off one charge of the still. The charge of wash produces about 10 or 12 per cent. of rum, at an average strength of 25 per cent. over proof.

In some of the islands a still makes about 220 gallons of rum daily; these are produced from about 530 gallons of low wines, or 113 of rum may be procured from 1200 gallons of wash. This liquor is so strong that olive oil will sink in it, and by one rectification it is made to approach the strength of alcohol. The process of distillation is in general slow, and much caution is observed in the condensation of the spirit. To provide against a scarcity of water, which often occurs in the islands, they preserve in large tanks a sufficiency of rain water to enable them to mix the molasses, &c., and to cool the worm of the still. As the water becomes heated in the worm-tub, it is carried to coolers or cisterns, and when cold it serves again for refrigeration. In most of the islands, the curing-houses for sugar and the distilleries for rum are constructed on the sides of canals, and the canes carried to them from the plantation, either in boats or by negroes. Five or six immense copper boilers are kept in each of these houses, and the greatest cleanliness is observed in the distillery; a precaution of immense importance, which must contribute largely to the strength and purity of the rum. In Jamaica the operations go on without intermission; the negroes being formed into divisions or relays, who relieve each other at regular intervals. The richness of flavour peculiar to Jamaica rum has rendered it famous in all parts of the world; this is undoubtedly derived from the raw juice and the fragments of the sugar-cane, which are mashed and fermented with the other materials in the tun. The essential oil of the cane is thus imparted to the wash, and carried over in the distillation. Sugar, when fermented and distilled by itself, yields a spirit in no way different from pure alcohol. Time adds much to the mildness and value of rum; the planters age it fictitiously by the addition of pine-apple juice.

A superior quality of rum is manufactured in the colony of Demerara, where distillation has been carried to a high state of perfection by the perseverance and skill of several scientific men, who have caused the rum of this district, and that of Essequibo, to be as much prized in the American market as Jamaica rum is in England. In Brazil large quantities of rum are manufactured, which are exported to America and to most European nations. The process followed is rude and simple. The wash is generally fermented in large earthen jars, but no fixed rules to regulate the quantity of molasses which should be operated upon are observed. A strong lie is poured on the syrup, in order to thicken and purify it, which is obtained by burning a plant of the *polygonum* species, called by the Indians *cataya*, and infusing the ashes in water. This plant has a bitter pungent taste, and is considered of use in making rum. The stills are mere earthen jars, with a long narrow neck, on the top of which is placed a head or cap, having at one side a pipe of about 6 inches long; to this adapter a copper tube, 4 feet in length, is connected, which passes through an earthen vessel sufficiently large to hold the water for the condensation of the spirit, and this contrivance is made to answer the purpose of both worm and worm-tub.

To calculate the cost of rum to the sugar planter is difficult; in general, it is estimated that one-fourth of the entire produce of a plantation may, in point of value, consist of rum, and accordingly one-fourth of the expenditure may be taken as the first cost of the rum, and the remaining three-fourths as that of the sugar. Some say that the charge of making rum bears a similar proportion to that of home-made spirits, but this is an erroneous assumption. Rum is made from the molasses, or that part of the cane-juice which will not crystallize into sugar, and also from the scum which is taken off during the saccharific process, and which in sweetness is equal to one-fifth of molasses. Take, as a standard, a distillery on a plantation producing 250 hogsheads of sugar, yielding 15,000 gallons of molasses, and scum equal to 5000 gallons, netting in all 20,000 gallons of molasses. These would produce about 15,000 gallons of proof rum, which, when brought to the British market, would be reduced by the voyage to about 13,500 gallons, the average loss being 10 per cent. These would cost the manufacturer throughout the islands from 1*s* 1*d.* to 1*s.* 4*d.* per gallon, independent of all charges for puncheons, freight, commission, and other unavoidable expenses.

From this statement it appears that the distiller of rum has little or no profit, but being the grower of the material, and having his capital embarked in the trade, he is compelled to manufacture it from necessity, and the sooner he can turn the article to account the better he is enabled to bear loss and meet his engagements.

In France a large quantity of spirit is annually manufactured from the molasses of the beet-root sugar factories, of which a great many exist in that country. The better sort of molasses remaining after the refining of the sugar of the colonies is too valuable to be converted into rum, but sometimes the inferior article is disposed of in this way. On the arrival of the molasses at the distillery, they are emptied into large cisterns perfectly free from any dampness which would cause them to ferment, and here they remain till required for use. The fermentation of molasses presents some difficulties; they must be properly mixed with water in such proportion that the resulting liquid will not exceed 8° of BEAUMÉ'S areometer, at a temperature of 20° C. = 68° Fahr., which should always be the heat of the mixture. When too little water is used the fermentation sets in too rapidly, the temperature becomes higher, and acetous fermentation speedily ensues. On the contrary, when too much water is employed the fermentation is inactive; in consequence of the low temperature a longer time is required, and generally bad results follow. These inconveniences can be overcome by attention to the directions about to be given.

It sometimes happens that the fermentation of the saccharine solution suddenly ceases, and cannot be revived by an increase of temperature or addition of a stronger solution of molasses. This is owing to the presence of lime and potassa, which are contained in almost all the molasses of beet-root sugar, and in consequence of the alkaline reaction imparted by these substances to the liquid, the conversion of the sugar into alcohol is interrupted. This anti-fermenting property of alkaline bodies is very easily removed; it suffices to add a certain quantity of sulphuric acid to neutralize them and form sulphates, in which state they are inert. A slight excess of acid might be employed without prejudice to the proper degree of attenuation, or to the taste of the product; for the molasses always contain salts of organic acids, with potassium, &c., which are decomposed by the sulphuric acid, and the organic acids are liberated. The sulphuric acid is to be added when the water is mixed with the molasses, and may vary in amount from half a per cent. of the weight of the latter, as a minimum, to 1½ per cent. as the maximum quantity. The molasses being comminuted with the water and acid, so that the solution stands at 8° of the areometer, about 2 per cent. of their weight of fresh barm, pressed and previously diluted with water, is added; the liquid is then strongly agitated and left to ferment. The fermentation is made in a number of tuns whose size corresponds with that of the distilling apparatus, and by this arrangement the distiller is enabled, when the fermentation in one tun is finished, to distil the contents directly.

The fermented wash should never remain longer than twenty-four hours before it is distilled. From this it is manifest that the distiller should be furnished with as many fermenting vessels as will permit him to have the contents of one tun daily ready for distillation, and one ready for charging each day; the intermediate tuns being in a higher state of fermentation as their turn brings them nearer the proper time of their being distilled. All the tuns should be well covered, to prevent the contact of the atmosphere and the acid fermentation taking place.

If molasses be fermented and distilled merely for the alcohol which they yield, the preceding directions relative to the proper dilution and strength upon the areometer answer best; some distillers, however, in addition to the alcohol, extract the alkaline salts; and in this case the preceding strength of 8° on the areometer would offer an inconvenience, inasmuch as a large amount of fuel would be consumed in evaporating the residuary liquid after the alcohol was expelled. To prevent such expenses for combustibles, an investigation was instituted to find out a means for fermenting the saccharine wash at a greater density than 8°, and the endeavour proved successful. The high density is 14° of the areometer, and in order to ferment such a solution without its passing to the acid fermentation the following mode is adopted:—When a sweet wash of 14° B. is set to ferment, the temperature of the liquid rises to 86° Fahr. (30° C.) in twenty-four hours, at which degree the alcohol is readily transformed into acetic acid. To oppose the formation of acetic acid, from the high temperature already mentioned, it is necessary, as soon as the liquid marks 76·6° Fahr. or 27° C., to divide it into two equal portions, and add to each half as much molasses of 14° strength as it already contains. Previous to mixing the second portion of molasses with the fermenting liquor, they should be well agitated with 2 per cent. of their weight of barm. Fermentation is now allowed to proceed without apprehension of the temperature rising so high as to favour the acetous fermentation in the liquor.

M. LAUGIER'S apparatus, which will be subsequently described, is expressly adapted for the distillation of fermented saccharine liquors, though wine and malt wash are also distilled in it. It works upon the same principle as DEROSNE'S still, under a simpler construction. In France, where considerable quantities of molasses are converted into rum, and this apparatus is in operation, the distillery is divided into the store-room, where the stock of molasses is retained until required for use; the fermentation-room, the still-room, and the store-room for the finished spirit.

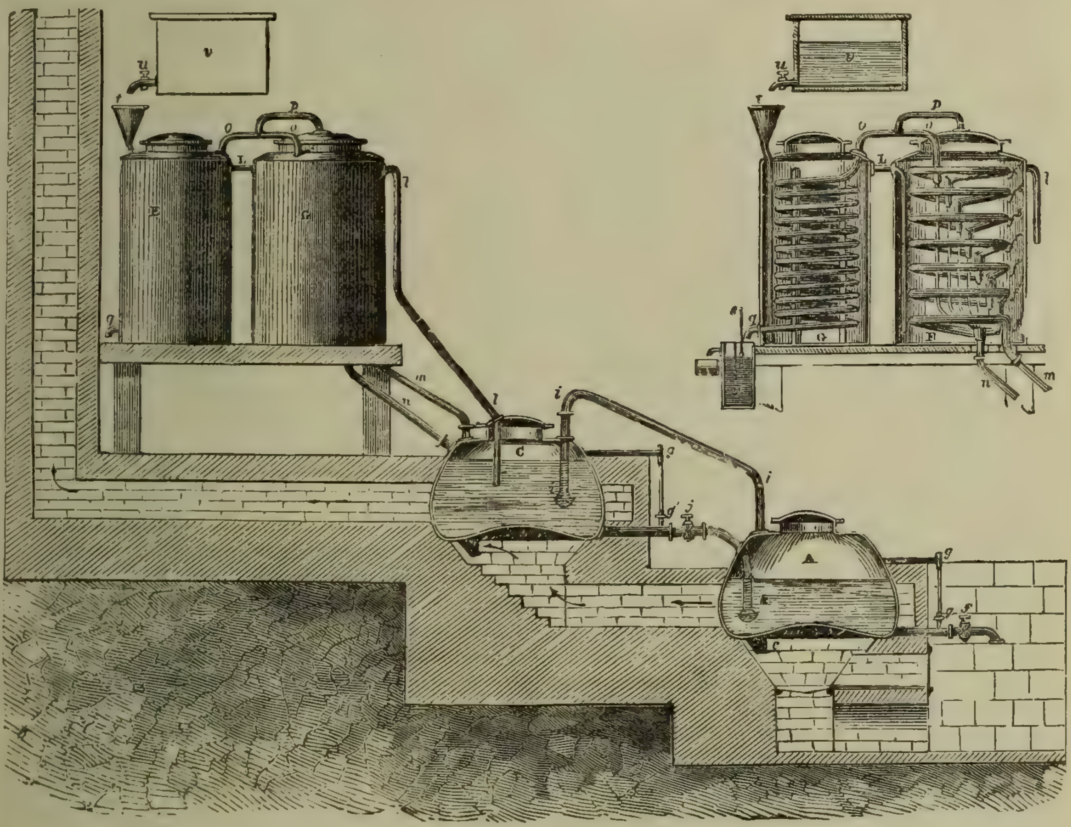
The fermenting tuns are of a size to correspond with the quantity of wash which the still is capable of working daily, and these tuns are worked in rotation, so that one may be worked off and ready for distillation each day; by this means the fermented liquor is prevented from being exposed to the air, and the formation of acetic acid wholly prevented.

A side view of the apparatus, as it appears set in brickwork, is seen in Fig. 47; A and C are sectional views of the boilers heated by the fire, *c*, under A, round which the flue passes; thence in the direction of the arrows round the second boiler, C, in a similar way, and afterwards into the chimney; G is the rectifying cylindrical vessel, and E the refrigerator where the spirit is condensed. The boiler, A, is furnished with two pipes; one of these is for discharging the contents when all the alcohol is expelled, and is furnished with a stopcock, *f*; the other pipe, *i i i*, carries off the generated vapour to the next boiler, C, where it terminates in a perforated rose, within a short distance of the bottom of the vessel.

A pipe issuing from the bottom of C, and furnished with a stopcock, *j*, enters the first boiler and terminates, like the pipe, *i*, in a perforated rose, as seen at *k*. From C, the pipes, *m*, *n*, and *l*, rise; *m* and *n* are connected with the rectifying apparatus in the cylindrical vessel, G; the former carries off the vapours generated in C, and the latter returns the liquid condensed in this vessel into the boiler. The pipe, *l*, serves to charge the boiler, C, from the rectifying apparatus. Two pipes, *o o* and L, unite the rectifier and the condenser; the former conducts the uncondensed vapours from the rectifier to the worm in the refrigerator, and the latter serves to replenish the vessel, G, with liquor from the refrigerator. The pipe, L, descends to within a short distance of the bottom of G, so as to have the colder liquid issuing in contact with the pipes which contain the warmer vapours. Another pipe, *p*, emerging from the cover of the rectifying vessel, conducts any vapour generated by the condensation in part of the distilled products of the boilers, A and C, to the condenser. The refrigerator is filled through the funnel tube, *t*, from the tank, *v*, by means of the pipe and stopcock, *u*.

Fig. 47.

Fig. 48.



The manner of working the still is simple:—Liquor is allowed to enter the funnel tube, *t*, until it begins to flow down the pipe, *l l*, into the boiler, C; and as soon as this is observed the stopcock, *j*, is opened, and the liquor admitted into the first boiler until it rises a few inches above the rose, *k*, as shown by the glass gauge, *g g*; the stopcock, *j*, is shut, and the liquor allowed to flow into C until it rises above the end of the pipe, *l l*, which emerges into the liquor; this is shown by another gauge pipe, *g′ g′*, attached to C. The stopcock, *u*, is now closed, and the fire urged under the first boiler, the contents of which very soon boil, and are partly converted into vapour, which is emitted to the next boiler through the pipe, *i i*. By means of the heat abstracted from the vapour in passing through the liquid, and that communicated to the boiler by the flue which circulates round C, the contents of this vessel are also made to boil, and, like those of A, are partly vaporized; the vapour is forced through the pipe, *m*, into the rectifying vessel, where, by means of a peculiar arrangement of pipes—to be explained further on—the greater part of the steam which is forced along from A and C is condensed, and falls back into the boilers through the pipe, *n*, to undergo a second distillation. The first portions of the vapour that enter this vessel are entirely condensed, in consequence of the liquid contained in it being as yet cold; but after a short time the heat of the condensing vapour raises the temperature of this liquid so high that it will not condense any longer the richer alcoholic vapour, and the latter rises through the pipe, *o o*, and enters the worm in the vessel, E, where complete condensation takes place, and the spirit produced flows out by the pipe, *q*. As soon as the liquor in the first boiler becomes exhausted the fire is slackened for a short time, the contents discharged through the pipe and stopcock, *f*, and a further quantity admitted by the pipe and stopcock, *j*, from the boiler, C, and this again replenished by opening the stopcock, *u*, of the tank, *v*. The fire is again urged briskly, and thus the distillation proceeds successively, so as not to lose alcohol.

Fig. 48 is a section of the rectifier and refrigerator: in the first there are seven compartments formed of large circular pipes, as seen at $f\ f'\ f''\ f'''\ f^5\ f^6\ f^7$, each one of which terminates in a smaller pipe that meets the others in a ball at the end of the pipe, *n*. *o o* shows the connection of this apparatus with the refrigerating worm in the vessel, G; *p*, the pipe connected with *o o*, and emerging from the cover of the vessel, E, for the purpose of carrying off any vapours generating in the liquid surrounding the apparatus in this vessel. *t* is the funnel pipe, reaching to the bottom of the refrigerator; and *q* the termination of the worm, by which the finished spirit is discharged into a small covered vessel, *r*, which contains an alcoholometer, *s*, to indicate the strength of the spirit.

The fermenting molasses are so viscous, when they are treated in such a way as to mark only 8° of the areometer, that at some period the mixture intumesces, so as to overflow the fermenting tuns, unless the latter be very large. To obviate this, some soft soap is added, which, being partly decomposed by the slight excess of acid contained in the liquid, the oily portion forms a layer which destroys the homogeneousness of the syrupy effervescence, and disposes the bubbles of carbonic acid to burst and pass off without much rising in the liquid. Fermentation is known to be finished when the action, after having been regularly increasing, ceases suddenly, and the temperature subsides. A sign by which a good fermentation is distinguished is the falling in of the head, and the diminution of specific gravity from 8° to 1° Beaumé.

If the liquid, after attenuation, be not immediately distilled, it is necessary to cool it down rapidly, to prevent its being converted into acetic acid. This is done either by passing cold water through a coiled pipe in the fermenting tun, or by emptying the whole into sulphured tubs, which resist the further action of any fermentation. Of the two methods the worm is preferable, as in a slow fermentation the transmission of hot water through this pipe would revive it; and when the temperature of the liquid becomes higher than what it should be, from a too rapid fermentation, it is equally opposed by pouring cold water through the worm. Laugier's apparatus is best adapted for the distillation of the fermented liquor of molasses.

The quantity of spirit obtained from molasses, when fermented at 14°, is less than when the mash is made to mark 8°; but considering the advantage of obtaining the alkaline matter, there is less evaporation, and consequently less fuel consumed. A method has been lately introduced by Dubrunfaut, by which the attenuation is made at 8°, and the saline matter obtained without much extra fuel. One part of this process is to employ the spent liquor, after distillation, for bringing a second portion of molasses to 8° of the areometer; this liquor has no injurious effect upon the fermentation, and offers the advantage of having double the quantity of salts in the same bulk of liquid.

This liquid he introduced into a steam boiler instead of water, for the purpose of generating steam to heat the liquid for distillation, and the apparatus. Finally, the evaporation is finished in three pans or boilers, which are partly heated by the waste heat from a reverberatory furnace. The degree of heat which the liquid has, before it is run into the fürnace, is 32°: 1000 kilogrammes of molasses afford from 100 to 140 kilogrammes of saline matter, marking 50° to 55° on the alkalimeter.

Potato Spirit.—Potatoes afford a considerable quantity of alcohol; and of late years the manufacture has been extensively conducted in France. There are two methods practised. In the first the starch of the potato is fermented without any previous preparation, and in the second the starch is converted into sugar by sulphuric acid. If a quantity of starch, no matter whether obtained from wheat or potatoes, be incessantly boiled with water acidulated with sulphuric acid for a few hours, occasionally adding water as it evaporates to preserve perfect fluidity; then saturated with lime, boiled to separate the sulphate of lime; and lastly, the solution be concentrated; a dark syrupy liquid is obtained, which on cooling affords abundance of sugar in crystals. This sugar certainly differs in some respects from common sugar; it is not quite so sweet, nor so soluble in water; it crystallizes differently, fuses at a much lower heat, and its solution ferments with great facility. It has been found that, during the whole process of its formation, not a bubble of gas is discharged, that the sulphuric acid remains unchanged, and that the contact of air is unnecessary.

There is produced from 100 parts of starch about 110 parts of sugar, which is converted by fermentation into alcohol. The advantages afforded by converting potatoes to this use are, that they are cheap and afford a good spirit, while the residuum of the distillation is good food for cattle; grain is economized and less yeast is consumed.

To obtain spirit according to the first process the potatoes are to be well steamed for an hour, and then bruised between two cylinders of wood or sandstone. Ground malt is mixed in a keeve with warm water, in quantity sufficient to give the consistency of thin pap, and the potato paste is then added, the whole being well stirred with a proper quantity of water until no lumps remain. The stirring is to be renewed at intervals until the mixture is cold. Natural yeast of beer, or that made artificially from rye, is introduced, but in less quantity than would be required for corn, since potatoes ferment more easily. Experience has proved that the addition of red beetroot or carrots to the potatoes and malt affords spirit of a better flavour and in larger quantity. When the fermentation has been pushed to its utmost the whole matter, both liquor and sediment, is introduced into the still, and distilled as in any other case, proper precautions being taken to prevent burning.

The process recommended by Siemen, and now applied in Denmark, is to heat 3 or 4 tons of potatoes in steam a little above 212° Fahr. (100° C.), then to mash them well by the rotatory motion of an iron cross in the same vessel wherein they are steamed, and to add hot water, alkalized with 1¼ lbs. of caustic potassa. All the mucilage, which in the boiled potatoes commonly remains insoluble, is by the addition of the alkali converted into a starch, which easily passes through the sieve, leaving the thin skin of the potato. The water is to be in such quantity as to make a thin paste; this being quickly cooled, yeast is added, and the process conducted in the usual manner. It is said that by this method the quantity of spirit from a given weight of potatoes is greatly increased: 50 hectolitres, 30 litres (137·64 imperial bushels) of potatoes, along with 8 hectolitres (22·12 imperial bushels) of ground malt, yield 9 hectolitres (198 imperial gallons) of spirit. Cadet states that 800 lbs. of potatoes will afford 30 lbs. of spirit, which at that time he calculated to cost the distiller 36 francs, and to sell for 48.

The process for procuring alcohol from potato sugar need not be particularly described. The sugar being once obtained from potato starch, it is easy to conduct the fermentation. During the conversion of the starch into sugar, a few drops of a solution of iodine in alcohol is frequently added to a small portion of the liquor, to see if the blue iodide of starch is formed; this reaction manifests itself as long as any undecomposed starch remains. From 50 kilogrammes (110·31 lbs. avoirdupois) of potato starch, converted into sugar by sulphuric acid, are obtained from 20 to 25 litres (4·4 to 5·5 imperial gallons) of alcohol, at 0·935.

According to Wunrich, starch requires but 1 or 2 per cent. of sulphuric acid to convert it into sugar, if the heat applied be a few degrees above 212° Fahr. (100° C.), and two or three hours are then sufficient to crystallize it. He applies steam heat in wooden vessels.

The yeast thrown up by potatoes during fermentation, even with one-fifth of their weight of barley, possesses but little energy, and is therefore not used in attenuating the potato wash.

In the experiments made under the personal inspection of Professor Oersted at Copenhagen, from 16½ to 17 quarts of spirit, at 50° of Tralles' alcholometer, were obtained from a ton of potatoes, making a fair allowance for that portion of the product due to the malt used in the maceration. This spirit had a good flavour, though the produce was inferior to that obtained by the French chemists. Muller asserts that an apparatus on Siemen's principle (Figs. 35, 36), the expense of which is about 250 Prussian dollars, is capable of producing 50 per cent. more spirit from potatoes than the apparatus generally used in Germany.

About the year 1832 Messrs. Calder, at Eyemouth in Berwickshire, distilled spirit from potatoes for some little time. The spirit, which had the flavour of hollands, was pure and good, and it was affirmed that no grain or malt was used in its preparation. The fermentation was described as beautiful, the head rising 7 or 8 feet like clouds of cotton; and when beaten down to the surface of the worts it rose again in the same majestic manner. The gravity worked at was 40°, and the attenuation was good. The potatoes were ground in a mill like a common pepper mill in shape, but made of sheet iron perforated like a grater. The pulp thus produced was mashed in the keeve with boiling water, and the extract ran off quite pure and freely. A sperge, or small worts of about 20° gravity, was obliged to be used, otherwise the worts at the noticed gravity of 40° could not be got off; the produce was good, as there was no deficiency. The spirit sent to the London market, when called grain spirit in the permits, was highly prized; when this error was corrected, and the product was denominated spirit distilled from potatoes, the price fell, and it was not so much in vogue. About the same time Jamieson of Fairfield, near Enniscorthy, commenced distilling from potatoes. They were sliced, dried on a corn-kiln, ground to flour, mixed in certain proportions with grain, and mashed in the ordinary manner. But the manufacture was abandoned in consequence of the opposition of the peasantry, through fear of a scarcity of the article of food.

From some late experiments, Dubrunfaut proposed to brew from the starch of potatoes an excellent beverage resembling French beer, the starch being macerated and fermented with hops. By fermenting the saccharized starch with honey instead of hops, a palatable liquor was made, having all the qualities of Louvaine beer. Potato starch, being free from any peculiar taste, seems capable of receiving flavour in its fermentation from any of those substances which are used to give their peculiar characteristic tastes to the various kinds of beer and home made wines.

Hare, having observed a strong analogy between the saccharine matter of the sweet potato and molasses, or the saccharum of malt, boiled a wort made from the potatoes, of 1060° specific gravity, with a proportionate quantity of hops for the space of two hours. It was then cooled to about 56° Fahr. (17°·7 C.), and yeast added. As far as could be judged, the phenomena of the fermentation and the liquor produced were precisely the same as if malt had been used. The wort was kept in a warm place until the temperature was 85° Fahr. (29°·4 C.), and the fall of the head showed the attenuation to be sufficient; yeast subsequently rose, which was removed by skimming. A further quantity of yeast was precipitated by refrigeration, from which the liquor being decanted, became tolerably fine for new beer, and resembled in flavour ale made from malt. It has been computed that 5 bushels of potatoes would produce as much wort as 3 bushels of malt, while the residue, as food for cattle, would be worth half as much as the potatoes.

In the opinion of some—particularly those who have not employed sulphuric acid in saccharifying the starch—the best time to use potatoes in distillation is in spring, when they begin to vegetate. The growth of the buds must be checked, as in the process of malting; and this is easily done by spreading them on a floor, and by subsequent turning, so as to deprive them of as much of their water as possible. When reduced to a pulpy consistence, diluted with boiling water, and drawn off and cooled to a proper temperature, the liquid is then fermented in the same manner as grain worts; and such has been the treatment observed by many who have tried the distillation of potatoes in this country. Sprouted potatoes produce as perfect farina in July as in December, and equal in quantity to what they would have yielded earlier in the season, being, according to Sir John Sinclair, about 14 lbs. per cwt.

It has been stated that potato apples give, by proper treatment, as much alcohol as an equal quantity of grapes, when bruised and fermented with one-eighteenth or one-twentieth of their weight of yeast.

From these details on the application of potatoes in the manufacture of spirit, persons may be induced to try experiments that might ultimately prove advantageous. If they proceed by reduction of the farina to a pulpy substance, the operation is simply by boiling; if by the production of starch, it may be mechanically effected at little expense and labour, either by pounding or grating, and elutriation with cold water.

In some parts of France the tuber of the Jerusalem artichoke—*Helianthus tuberosus*—has been used for the purpose of distillation. The wash extracted from this vegetable, when fermented in the ordinary way, is found to yield a very pure and strong spirit, which is said to resemble that obtained from the grape more than any other substance that has hitherto been tried.

The root grows luxuriantly almost in every climate, but it does not appear that it has been cultivated much in England, either for the production of spirit or other uses; it might be remunerative in this particular, in producing a medium beverage between genuine French brandy and the fiery spirit extracted from grain, and sold as gin and whisky.

Arrack, contracted into rack, is a spirituous liquor from the East Indies. The name is used in the East to signify any alcoholic liquor; but that usually bearing this name is a liquid distilled from *toddy*, the juice of the cocoa-nut tree, *cocos nucifera*, and procured by incision. In all countries where rice is abundant, an alcoholic liquor is distilled from it, called *arrack* or *rack*. Goa and Columbo arrack are always made from toddy; Batavia and Jamaica arrack from molasses and rice, with a little toddy. The Pariah arrack contains *cannabis sativa* and a species of *Datura*, which render it more inebriating; it is not, however, certain whether the Pariah arrack is used generally to imply a sophisticated spirit, or is only applicable to that liquor with which the above ingredients have been compounded.

The process is nearly the same as that for making grain spirit. Rice is put into a vat, covered with water, and agitated. A handful is from time to time taken from different parts of the vat, and germination is allowed to proceed until at least half of it has sprung. The operation may be hastened by adding lukewarm water, and drawing a certain quantity from the top, heating and returning it to the vat, the contents of which are well stirred. Great caution is necessary in doing this, for much risk is run of breaking the seed, which would make the rice decay, and hinder the fermentation of the rest. If such a thing occurs, the injured grain might be extracted, but this would be attended with so much labour, as compared to the value of the rice, that commonly the whole is rejected by distillers, and sold for the use of cattle. To avoid these mishaps, a man accustomed to the work is employed. He introduces the rake just below the surface of the rice, agitates the water in turning, and stirs gently till he reaches the bottom; the same caution is observed in bringing the rake again to the surface. When fully half of the rice is germinated, the plug at the under part of the vat is withdrawn to let out the water; the rice is then removed to a room, and heated like the barley in the distillation of the grain spirit. It is submitted to a heat of 59° Fahr. (15° C.), which finishes the germination.

The subsequent operations are the same as those pursued by the brewer. When the rice has sufficiently acquired the vinous fermentation, it is introduced into the still, and treated like the other substances discussed.

In India, when the material for distilling, whether rice or the simple fermented juice of the *cocos nucifera*, is ready, a hole is dug in the earth, suited to the size of the still to be used. On a level with the bottom of this hole there is an underground communication made for the purpose of feeding the fire with atmospheric air; near the edge of this orifice is a chimney, serving both for the supply of the fuel and for the escape of the smoke; a fire of dry wood is first lit, and when the ground is completely heated, the still is fixed in it, and so bound round with earth as to prevent the escape of any heat. When ebullition commences, and the steam begins to ascend, an

Indian pours a gentle stream of water either upon the head of the still or on the broad and thin surface of a plate of tin or copper, with a gutter for the water to run off, which is fixed on a pan, with a hole in the bottom, and luted to the neck of the still to serve as a condenser, The extreme cold produced by the evaporation of the water on so broad a surface, occasions the vapour from the still to be immediately condensed, and to flow in a trickling stream into the receiver.

A lady who resided in India thus describes the working of a native still which she had an opportunity of seeing :—The still was simply constructed : round a hole in the earth a ledge of clay four inches high was raised, with an opening half a foot in width for the purpose of supplying fuel. Upon the clay a large earthen pot was luted ; to its mouth was closed with lute the mouth of a second pot ; and where they joined, an earthen spout a few inches long was inserted, which served to let off the spirit condensed in the upper jar, the latter being kept cool by a person pouring water constantly upon it. In the cottage, or still-house, was a woman employed in cooling the still by pouring water on it from a cocoa-nut ladle. The woman said that she sat at her occupation from sunrise to sunset, without scarcely a change of position, while her husband constantly brought toddy for distillation.

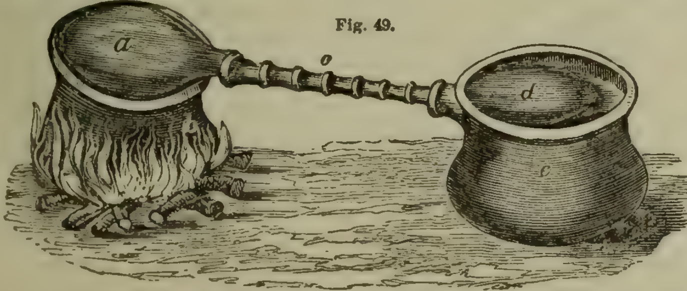
Arrack is drunk in Siam ; but its consumption, as well as its manufacture, is confined to the Chinese residing in that country. It is stated that the privilege for its distillation brings to the government £58,000 per annum for the whole kingdom. The greater portion of arrack is distilled at Bangkok, the capital ; and the remainder at thirteen of the principal towns.

A strong kind of arrack, possessing an unpleasant smell, is distilled from palm wine, &c. ; this spirit is called *vellipatty;* another sort is known under the name of *talwagen.* The revenue arising from arrack in Ceylon is very large ; in the land-rents are included the duties on cocoa-nut trees, which exceed those on rice by nearly £15,000 annually.

Arrack, from time immemorial, has been a common beverage among the Cingalese, though their method of manufacturing it is very rude.

The still they employ is of earthenware, and of the simplest construction ; the subjoined is a representation of the one in general use :—

Fig. 49.



a, *b*, are the capital and alembic luted together ; *d*, *e*, a receiver and a refrigerator, in one piece, the former connected with the head by a bamboo, *c*.

Ardent spirit is manufactured in much larger quantities in Java than in any other island in the Indian ocean, which may, no doubt, be accounted for by the great industry of the Dutch, and the celebrity which the Batavian arrack so early acquired under their patronage.

It is made in the following manner :—About 70 lbs. of *ketan*, or glutinous rice, are heaped up in a small vat ; round this heap 100 cans of water are poured, and on the top 20 cans of molasses ; after remaining two days in this vat, the ingredients are removed to a larger vat adjoining, when they receive the addition of 400 cans of water and 100 of molasses. Thus far the process is carried on in the open air. In a separate vat within doors, 40 measures of palm wine, or toddy, are immediately mixed with 900 of water and 150 of molasses, both preparations being allowed to remain in this state during two days. The first of these preparations is carried to a still larger vat within doors ; and the latter, being contained in one placed above, is poured upon it through a hole bored for the purpose near the bottom. In this state the entire preparation is allowed to ferment for two days, when it is poured into small earthen jars, containing about 20 cans each, in which it remains for the further period of two days, and is then distilled. The proof of a sufficient fermentation is obtained by placing a lighted candle or taper about 6 inches above the surface of the liquor in the fermenting vat ; if the process be sufficiently advanced, the carbonic acid extinguishes the light.

Another mode of apportioning the materials for the making of arrack is—

62 parts molasses,
3 do. toddy,
35 do. rice.

These yield, on distillation, 23½ parts of proof arrack. The stills are made of copper, and are much like those used in the West Indies ; the worms consist of about nine turns of Banca tin. The spirit runs into a vessel under ground, whence it is poured into proper receivers, and is called the third, or common sort of arrack, which by a second distillation in a smaller still, with the addition of some water, becomes the second sort ; and by a third operation, is what is called the first sort. To ascertain the strength of the spirit, a small quantity of it is burned in a saucer, and the liquid remaining measured; the difference between the original quantity and the residue gives the measure of the alcohol lost. The completion of the first sort does not require more than ten days, six hours being sufficient for the original preparation to pass through the first still. The Chinese residents, who conduct the whole of this process, call the third, or common sort, *sichew ;* the second, *tanpo ;* and the first, *kiji.* The latter two are distinguished as arrack *api.* When cooled, it is poured into large vats in the storehouses, where it remains until put into casks.

The making of arrack is distinct from that of sugar, which is manufactured to a great extent in Java. The arrack distillers purchase the molasses from the sugar manufacturers.

A very large quantity of arrack is consumed in the East; 700,000 gallons are annually exported from Ceylon, of which upwards of 30,000 come to England.

CARROT SPIRIT.—In the Transactions of the Royal Society of Edinburgh is a paper by HUNTER and HORNBY, in which they give the details of the process for the production of the above spirit. With the paper was sent a sample of the spirit, and the society appointed BLACK, HUTTON, and JAMES RUSSELL to investigate this account, together with the specimen of the spirit, and to report upon the same, which they did as follows:—

The sample of spirit which was sent by Dr. HUNTER, of York, to the Royal Society, has been examined, and also the account of the experiment on the fermentation and distillation of carrots, by which the spirit was produced. The experiment was made by Mr. THOMAS HORNBY, druggist in York, with 1 ton and 8 stones of carrots, which, after being exposed to the air a few days to desiccate, weighed 160 stones, and measured 42 bushels; they were affused with water, topped and tailed, by which they lost in weight 11 stones, and in measure 7 bushels; and being then cut, were boiled with the proportion of 24 gallons of water to one-third of the above-mentioned quantity of carrots, until the whole was reduced to a tender pulp, which was done by three hours' boiling. From this pulp the juice was readily extracted by means of a press, and 200 gallons of juice were produced from the whole quantity.

The juice was reboiled with 1 lb. of hops for five hours, and then cooled to 66° Fahr. (18°·8 C.), and 6 quarts of yeast being added, it was set to ferment. The strong fermentation lasted forty-eight hours, during which time the heat abated to 58° Fahr. (14°·4 C.); 12 gallons of unfermented juice, which had been reserved, were then heated and added to the liquor, the heat of which was thus raised again to 66° Fahr. (18°·8 C.), and the fermentation was renewed for twenty-four hours more, the air of the brew-house being all this time at 44° and 46° Fahr. (6°·6 and 7°·7 C.) The liquor was now turned, and continued to work three days from the bung; lastly, it was distilled, and the first distillation was rectified next day without any addition. The produce was 12 gallons of spirits. It resembled the best corn-spirit in flavour, and was proof. The refuse of the carrots weighed 48 stones, which, added to the tops and tails, made provision for hogs, besides the wash from the still, which measured 114 gallons.

From the above, Dr. HUNTER draws the annexed comparison between the distillation of carrots and grain:—

Twenty tons of carrots will make 200 gallons of proof spirit. Eight quarters of malt, or rather materials for distillation, consisting of malt, wheat, and rye, will also yield 200 gallons of proof spirit. The refuse from the carrots will be 960 stones, which, at one penny per stone, will sell for £4. The refuse or grains from the malt, &c., will be 64 bushels, each bushel about 3 stones, which, at one penny per stone, will sell for 16*s*. The doctor, however, supposes that the manufacture of the spirit from carrots may be attended with more expense than that from malt, but imagines that the greater value of the refuse may compensate for that expense, and that the saving of corn for other purposes is an object worthy of attention and of encouragement.

MILK SPIRIT.—The Tartars and Kalmouks prepare a spirit from the milk of mares or cows, which they greatly relish: 21 lbs. of milk yield 1½ ounces of an insipid distillate, and 40 ounces of spirituous liquor; the latter, when rectified, gives 6 ounces of alcohol. OSERETSKOWSKY says that skimmed milk, when deprived of its butyraceous portions, neither produces spirit *per se*, nor by the addition of a ferment. Secondly, milk retaining a portion of its cream, agitated until it commences fermentation, produces alcohol, but in small quantity. Thirdly, the entire milk kept in a close vessel, which by agitation commences fermenting, furnishes more spirit. Nearly the same amount of spirit is procured from the same milk, when a ferment is added to it. Fourthly, milk deprived of the most part of its caseine furnishes very little spirit. Fifthly, when the serous part only of the milk is distilled, it affords little spirit. Sixthly, milk which is fermented in a close vessel, and left for some time, loses its acid, and furnishes much more spirit than it would do if distilled immediately. Seventhly, if the heat of the fermented milk be sustained, the alcoholic portion passes into vinegar.

MADDER SPIRIT.—Within the last few years a patent has been taken out in France by JULLIEN, for distilling a spirit from the washings of madder, which were previously allowed to run waste. Several madder distilleries are now established in France, and one has been lately erected in Glasgow by Mr. J. HINSHAW, of the firm of Messrs. ARTHUR and HINSHAW.

To explain the economy of this remarkable process, it may be stated that the madder is imported into this country in the form of a root, which somewhat resembles liquorice, or the stem of heather. To prepare it for the dyer, and especially for dyeing the celebrated turkey red, which has long been a staple business in Glasgow, the root is first roasted or kiln-dried; it is then ground into a coarse powder by two large cylinders of stone, revolving in a vertical position, like those used for crushing linseed-cake; in this state it is washed and subjected to hydrostatic pressure, to free it from the saccharine and other matters which would injure its dyeing qualities. When properly washed, it is again dried, and submitted to the action of another pair of stone cylinders, until it is reduced to an impalpable powder.

The washings of the madder at the dye-stuff factory of Messrs ARTHUR and HINSHAW were formerly permitted, as in other establishments, to flow into the nearest canal or other reservoir of refuse; but now it is carefully preserved, and distilled into a strong spirit, which, although more volatile and less agreeable to the taste than that distilled from malt or raw grain, may perhaps be found equally useful for various manufacturing purposes.

The process of the fabrication is exceedingly simple: mere washing of the madder supersedes the mashing of the grain or malt in common distilleries. The root being dried and ground, as already stated, is mixed in a series of vats with the requisite proportion of cold water, or water at the ordinary temperature. These vats are 3 feet deep by 5 or 6 in diameter. The mixture is effectually rummaged by the workmen with instruments resembling large hoes, the madder being kept in a state of diffusion in the liquid until it is conceived that the saccharine matter is entirely extracted. The liquor is then drawn off by sluices, and the vats being lined with coarse cloth, it percolates through that medium as a filter, leaving the madder behind, to be again carefully collected, dried, and finally ground for the use of the dyer.

When the madder liquor, or worts, is drawn off, it is let into a kind of under-back, from which it is immediately pumped up into a large fermenting tun: 2 tons of madder are found in practice to yield 2500 gallons of liquor, or madder worts, of a density equivalent to 30° by Allan's saccharometer.

The fermenting tun being filled by the produce of several washings, has usually begun to ferment before it receives the liquor from the last washings. It is not a little remarkable, that this fermentation of the madder liquor commences and proceeds spontaneously, without the addition of yeast or the application of heat. No ferment of any description is added, and the water used throughout the entire process, up to the point of distillation, is at the ordinary temperature. The addition of yeast has been tried, but without any sensible advantage, either in promoting the fermentation or increasing the ultimate yield of spirits. In consequence, however, of the spontaneous character of the process, the fermentation is slower than usual, averaging from six to eight days to a proper attenuation. This is conceived to be accomplished when the gravity of the worts is reduced from 24° to 12°.

From the fermenting tun the wash is immediately run into the still, and the rest of the operation proceeds as in the distillation of malt or raw grain whisky. The still used is STEIN'S patent, and is somewhat similar to COFFEY'S, but rather more complex in its arrangements, and possessing the undoubted advantage that it may be applied, with equal efficiency, either to the distillation of malt or raw grain whisky. From this still the madder spirit is drawn off at one operation; it may be run weaker or stronger, but is generally taken from the still about 60° to 64° over proof by Sikes' hydrometer.

The produce from 2 tons of madder, yielding, as has been stated, 2500 gallons of liquor at 30°, is about 60 gallons of spirit.

The berries of the *Sorbus Aucuparia* have been used in the North of France for the production of spirit, and the result is said to be equal to the purest distillation from grapes for brandy. The berries, when perfectly ripe, are first exposed to the action of cold in the open air, then put into a wooden vessel, bruised, and boiling water poured on, the menstruum being stirred until it has sunk in temperature to 82° Fahr. (27°·7 C.). A proper quantity of yeast is then added, the whole covered and left to ferment. When the action has terminated, the liquor is put into the still, and drawn over in the usual way. The first running is weak and disagreeable in flavour, but being distilled from very fresh finely-powdered charcoal, in the proportion of 8 or 9 lbs. to 40 gallons of weak spirit, a fine product is obtained. The charcoal should remain in the liquid two or three days before the second distillation.

ALCOHOLOMETRY.—This is the process of ascertaining the centesimal quantity of anhydrous alcohol in a spirituous liquid. It is generally accomplished by determining the specific gravity of the liquid, but it is in this case absolutely necessary that only alcohol and water should be present. The quantity of alcohol in spirit containing much volatile oil or saccharine matter, &c., cannot be at once found by its specific gravity.

It happens sometimes that only small quantities of the alcoholic fluid is at command. In such a case it is impossible to obtain a correct result by determining the specific gravity of the few drops of alcohol obtained by distillation. It is then safer to subject the alcohol to organic analysis by combustion with oxide of copper, and to calculate the quantity of absolute alcohol from the resulting carbonic acid and water. This is of course only applicable when the alcohol does not contain other volatile hydrocarbons.

With the view of being able to calculate the absolute alcohol included in a spirituous liquid from its specific gravity, it was deemed advisable to mix anhydrous alcohol and water in the different proportions, and by experiments, to establish with certainty the specific gravity of these mixtures. Such experiments have been gone through at distinct periods; the most accurate and complete were those performed by GILPIN. They were undertaken by Sir CHARLES BLAGDEN at the instance of the British government, it being of course a matter of great importance to the excise that extreme accuracy should be attained in all determinations, and that their decisions should be above dispute. These determinations were made by GILPIN under Sir CHARLES BLAGDEN'S direction, and were first given to the world in 1790. In order to insure their correctness they were subsequently twice repeated, and were ultimately published in the Philosophical Transactions of the Royal Society in 1794.

The method adopted was to weigh the mixture of alcohol and water in a long-necked flask, which was filled up to a mark showing the bulk of a known weight of water. The specific gravity of forty mixtures was thus determined, each one at fifteen different degrees of temperature. Alcohol of specific gravity 0·82514 was used, which was taken as being 0·825, the requisite allowance being made in the tables. From GILPIN'S conclusions, aided by results of his own, TRALLES constructed the tables appended.

The percentage of absolute alcohol may be stated by one of two methods; namely, by weight or volume.

Liquors being vended by measure and not by weight, the centesimal amount by volume is usually preferred. But as the bulk of liquids generally, and particularly that of alcohol, increases by heat, it is necessary that their reputed richness should have reference to some normal temperature; this standard, as fixed by TRALLES in the construction of his tables, is 60° Fahr.

The percentage by weight remains the same at all temperatures, while the per cent. by volume varies with the temperature of the liquid; and this entails the necessity of having the sample, in the course of being tested, reduced to the standard degree of the table by calculation or otherwise. In the subjoined table water at 39°·8 Fahr., being its maximum density, is taken as the standard for specific gravity, and is put as 1·000, which, at 60° Fahr., equals ·9991.

TRALLES' TABLE 1.

Per cent. of alcohol, by volume.	Spec. grav. of the liquid at 60°.	Difference of the spec. gravs.	Per cent. of alcohol, by volume	Spec. grav. of the liquid at 60°.	Difference of the spec. gravs.
0	0·9991		51	0·9315	20
1	9976	15	52	9295	20
2	9961	15	53	9275	20
3	9947	14	54	9254	21
4	9933	14	55	9234	20
5	9919	14	56	9213	21
6	9906	13	57	9192	21
7	9893	13	58	9170	22
8	9881	12	59	9148	22
9	9869	12	60	9126	22
10	9857	12	61	9104	22
11	9845	12	62	9082	22
12	9834	11	63	9059	23
13	9823	11	64	9036	23
14	9812	11	65	9013	23
15	9802	10	66	8989	24
16	9791	11	67	8965	24
17	9781	10	68	8941	24
18	9771	10	69	8917	24
19	9761	10	70	8892	25
20	9751	10	71	8807	25
21	9741	10	72	8842	25
22	9731	10	73	8817	25
23	9720	11	74	8791	26
24	9710	10	75	8765	26
25	9700	10	76	8739	26
26	9689	11	77	8712	27
27	9679	10	78	8685	27
28	9668	11	79	8658	27
29	9657	11	80	8631	27
30	9646	11	81	8603	28
31	9634	12	82	8575	28
32	9622	12	83	8547	28
33	9609	13	84	8518	29
34	9596	13	85	8488	30
35	9583	13	86	8458	30
36	9570	13	87	8428	30
37	9556	14	88	8397	31
38	9541	15	89	8365	32
39	9526	15	90	8332	33
40	9510	16	91	8299	33
41	9494	16	92	8265	34
42	9478	16	93	8230	35
43	9461	17	94	8194	36
44	9444	17	95	8157	37
45	9427	17	96	8118	39
46	9309	18	97	8077	41
47	9391	18	98	8034	43
48	9373	18	99	7988	46
49	9354	19	100	7939	49
50	9335	19			

The third column of this table exhibits the differences of the specific gravities, in order to facilitate the calculation of fractions of percentage for specific gravities intermediate between those stated in the table—the difference in the densities, as given in the third column, becoming the denominator of the fraction, and the variation between the next and greatest specific gravity in the table and that of the liquid in question forming the numerator. To illustrate this method of calculation by an example, let it be supposed that the specific gravity of a liquid was found to be ·9260 at 60° Fahr., which numbers, according to the table, would indicate a percentage of alcohol between 53 and 54, or 53 and a fraction whose numerator is the difference between ·9275, the specific gravity of an alcohol 53 per cent., and ·9260, which difference equals 15; this number forms the numerator of the fraction, whose denominator is the difference between the specific gravities of the liquids containing 53 and 54 per cent. of alcohol, and which in the foregoing table is 21; hence the value of the liquid, specific gravity ·9260, is $53\frac{15}{21}$, or 53·71 per cent.

The content, by weight, of alcohol in a liquid, the centesimal value of which per volume has been found, is ascertained by a simple calculation. This operation is done by multiplying the content per volume of alcohol into the specific gravity of absolute alcohol, and dividing the product by the specific gravity of the liquid. An example will aid the reader in comprehending the manner of performing the work:—Suppose an alcohol of 50 per cent. by volume, whose density, according to the preceding table, is ·9335. Absolute alcohol in the table is ·7939, and this multiplied by 50, and the product divided by ·9335, gives the percentage by weight, thus:—

$$\cdot7939 \times 50 = 39\cdot6950 \div \cdot9335 = 42\cdot5227 \text{ per cent.}$$

It necessarily happens that alcoholic liquors are seldom at the very degree of the thermometer at which the preceding table has been drawn up, and as it is difficult to bring the sample to mark 60° Fahr., TRALLES, for the purpose of surmounting this obstacle, constructed another table, wherein the volume of alcohol is given corresponding with the temperature of the liquid at the time of the experiment.

TRALLES' TABLE II.

Per cent., by volume, of absolute alcohol.	Spec. grav. of the liquid at 60°.	Increase of spec. grav. at the indicated temperature *below* 60°.					
		+ 55°	50°	45°	40°	35°	30°
0	0·9991	4	7	9	9	9	7
5	9919	4	7	9	10	10	9
10	9857	5	9	12	14	15	15
15	9802	6	12	17	21	23	25
20	9751	8	16	23	29	35	39
25	9700	10	21	31	39	48	56
30	9646	13	26	39	51	62	73
35	9583	16	31	46	61	75	89
40	9510	18	35	52	70	87	103
45	9427	19	39	57	76	94	112
50	9355	20	40	60	80	99	118
55	9234	21	42	63	84	104	124
60	9126	22	43	65	86	107	127
65	9013	22	45	67	88	109	130
70	8892	22	45	68	90	112	133
75	8765	23	46	68	91	113	135
80	8631	23	47	70	92	115	137
85	8488	23	47	70	93	116	139
90	8332	24	48	71	94	117	140

TRALLES' TABLE II.—Concluded.

Per cent., by volume, of absolute alcohol.	Spec. grav. of the liquid at 60°.	Decrease of spec. grav. at the indicated temperature above 60°.							
		65°	70°	75°	80°	85°	90°	95°	100°
0	0·9991	1	11	17	24	32	40	50	60
5	9919	1	11	18	25	33	42	51	62
10	9857	6	13	20	29	37	47	57	68
15	9802	7	15	25	34	44	55	67	79
20	9751	9	19	30	41	53	66	79	93
25	9700	11	24	36	50	63	78	93	109
30	9646	14	28	43	59	75	91	108	125
35	9583	17	33	50	68	86	104	122	141
40	9510	18	37	56	75	94	114	136	154
45	9427	20	40	60	80	101	122	143	154
50	9335	21	42	63	84	106	128	150	173
55	9234	22	43	65	87	109	132	155	178
60	9126	22	44	67	90	113	136	159	183
65	9013	22	45	68	92	115	138	162	187
70	8892	23	46	69	93	117	141	165	190
75	8765	23	46	70	94	119	143	167	192
80	8631	23	47	71	96	120	144	169	194
85	8488	24	48	72	96	121	145	170	195
90	8332	24	48	72	97	121	146	171	196

A further objection to these tables is, that the specific gravity of the mixtures of alcohol and water at elevated or reduced temperatures is not the real but the apparent density. The cause of this discrepancy is, that the glass or copper vessel in which the liquids are weighed are liable to expand or contract with change of temperature,

TRALLES constructed a third table, in order that the percentage by volume in an alcoholic liquid might be ascertained from the more uniform arrangement of the numbers denoting the specific gravities.

In Table III. the densities are given of the several mixtures from 30° to 85°, as ascertained by a glass instrument; but these numbers, by the aid of the allowance, as seen in Table IV., can be made to correspond with the indications of a brass alcoholometer.

The necessity for using Table IV. arises from the discrepancy in the contraction or expansion of glass or brass at different temperatures, occasioning variation in the density; hence these numbers must be added or subtracted, as directed, according to the temperature, when a brass instrument is employed.

TRALLES' TABLE III.

Per cent. of alcohol, by volume.	Specific gravity of the liquid, ascertained by glass instruments, at the indicated temperatures.											
	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°
0	·9994	·9997	·9997	·9998	·9997	·9994	·9991	·9987	·9981	·9976	·9970	·9962
5	9924	9926	9926	9925	9925	9922	9919	9915	9909	9903	9897	9889
10	9868	9869	9868	9867	9865	9861	9857	9852	9845	9839	9831	9823
15	9823	9822	9820	9817	9813	9807	9802	9796	9788	9779	9771	9761
20	9786	9782	9777	9772	9766	9759	9751	9743	9733	9723	9713	9701
25	9752	9745	9737	9729	9720	9709	9700	9690	9678	9666	9653	9640
30	9715	9705	9694	9683	9671	9658	9646	9633	9619	9605	9590	9574
35	9668	9655	9641	9627	9612	9598	9583	9567	9551	9535	9518	9500
40	9609	9594	9577	9560	9544	9527	9510	9493	9474	9456	9438	9419
45	9535	9518	9500	9482	9464	9445	9427	9408	9388	9369	9359	9329
50	9449	9431	9413	9393	9374	9354	9335	9315	9294	9274	9253	9232
55	9354	9335	9316	9295	9275	9254	9234	9213	9192	9171	9250	9128
60	9249	9230	9210	9189	9168	9147	9126	9105	9083	9061	9039	9016
65	9140	9120	9099	9078	9056	9034	9013	8992	8969	8947	8924	8901
70	9021	9001	8980	8958	8936	8913	8892	8870	8847	8825	8801	8778
75	8896	8875	8854	8832	8810	8787	8765	8743	8720	8697	8673	8649
80	8764	8743	8721	8699	8676	8653	8631	8609	8585	8562	8538	8514
85	8623	8601	8579	8556	8533	8510	8488	8465	8441	8418	8394	8370
90	8469	8446	8423	8401	8379	8355	8332	8309	8285	8262	8238	8214

TRALLES' TABLE IV.

To be subtracted.						To be added.					
30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°
·0005	·0004	·0003	·0002	·0002	·0001	—	·0001	·0002	·0002	·0003	·0004

It occurs that liquids are tested whose temperature and specific gravity are intermediate between those instanced in the preceding table, and in this case the corresponding content of alcohol must be found by calculation. To give an example:—Let it be supposed that the specific gravity of an alcoholic solution has been found by experiment to be ·9320 at a temperature of 72° Fahr. In the column under 70°, the specific gravity ·9388 is that which is next over the above number, and in the column under 75° the gravity nearest to it is ·9369, both of which exceed ·9320—the former by ·0068, and the latter by ·0049. The difference between these two numbers is ·0019, which is the variation for 5°, or between 70° and 75°, and by dividing by 5, the quotient is $\frac{\cdot 0019}{5}$, the difference for each degree. As the temperature of the liquid under examination is 72°, or 2° over 70°, it is necessary to reduce the specific gravity to what it would indicate were the liquid at 70°, by adding a multiple of $\frac{\cdot 0019}{5}$ by 2, or $\frac{\cdot 0038}{5} = \cdot 0007\frac{3}{5}$ to the specific gravity obtained—·9320—which would make it $\cdot 9327\frac{3}{5}$, or omitting fractions, ·9327. By referring to the table, will be seen in the horizontal column opposite 45 per cent. of alcohol, and under 70°, the specific gravity ·9388, and in the same column, in a line with 50 per cent. of spirit, ·9294, whose difference from the foregoing is ·0094; thus the variation in gravity at the same temperature, for 5 per cent. of alcohol, is ·0094. In like manner, the difference of ·9388 and ·9327, the reduced gravity for the liquid specified, is ·0061; and since 5 per cent. of spirit has been shown to correspond with ·0094, it is found by simple proportion that ·0061 will be equivalent to 3·24 per cent., and this, added to 45 per cent., the spirit in the liquid of gravity next preceding that which is supposed to be ascertained, gives 48·24 as the percentage by volume of alcohol. Numerically—

$$\cdot 9388 - \cdot 9320 = \cdot 0068, \text{ and}$$
$$\cdot 9369 - \cdot 9320 = \cdot 0049.$$

By subtracting the lesser of these from the greater, namely, ·0068 — ·0049 = ·0019, the difference for the 5° between 70° and 75° Fahr., giving for each degree $\frac{\cdot 0019}{5}$; and to reduce the corresponding gravity of the liquid at 72° to that of 70°, there must be added to it $\frac{\cdot 0019}{5} \times 2\ (= 72 - 70) = \frac{\cdot 0038}{5} = \cdot 0007\frac{3}{5}$; and thus one obtains $\cdot 9320 + \cdot 0007\frac{3}{5} = \cdot 9327\frac{3}{5}$, or omitting fractions, ·9327. Again,

$$\cdot 9388 - \cdot 9294 = \cdot 0094, \text{ and}$$
$$\cdot 9388 - \cdot 9327 = \cdot 0061.$$

And since the former indicates a difference of 5 per cent. in the amount of alcohol, at the same temperature, the equivalent for ·0061 under similar circumstances is obtained by simple proportion :—

As 94 : 5 : : 61 : 3·24, which, when added to 45, gives 48·24, the content per cent. by volume of alcohol in the liquid. From all the tables in the foregoing for the determination of the volume of alcohol in a liquid, at whatever temperature it may stand, it is seen that reference is always had to the percentage at the normal temperature of 60° Fahr. Hence, in examining an alcoholic liquid for its true content of pure alcohol, the heat must be diminished to 60°, or else the temperature noted at the time of experiment, and then by calculation reduced to 60°; or the content of alcohol at 60° may be found as in Table II., where the specific gravity at the different temperatures is in inverse proportion to the volume of alcohol.

To avoid this calculation, TRALLES calculated another table, which gives the content in volume of absolute alcohol in a liquid, reference being had to the bulk of the liquid at the temperature at which it is measured.

For the prevention of error, it is absolutely necessary to determine the specific gravity of the liquid at the same degree at which it stands when measured; a glass instrument should be employed.

TRALLES' TABLE V.

To ascertain at any temperature, from the specific gravity, the quantity of absolute alcohol in a liquid expressed in volume centesimally, at the indicated temperature.

Per cent. of absolute alcohol in the liquid as measured.	Specific gravity of the liquid, ascertained by glass instruments, at the indicated temperatures.											
	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°
0	0·9994	·9997	·9997	·9998	·9997	·9994	·9991	·9987	·9981	·9976	·9970	·9962
5	9924	9926	9926	9926	9925	9922	9919	9915	9909	9903	9897	9889
10	9868	9869	9868	9867	9865	9861	9857	9852	9845	9839	9831	9823
15	9823	9822	9820	9817	9813	9807	9802	9796	9788	9779	9771	9761
20	9786	9782	9777	9772	9766	9759	9751	9743	9733	9722	9711	9700
25	9753	9746	9738	9729	9720	9709	9700	9690	9678	9665	9652	9638
30	9717	9707	9695	9684	9672	9659	9646	9632	9618	9603	9588	9572
35	9671	9658	9644	9629	9614	9599	9583	9566	9549	9532	9514	9495
40	9615	9598	9581	9563	9546	9528	9510	9491	9472	9452	9433	9412
45	9544	9525	9506	9486	9467	9447	9427	9406	9385	9364	9342	9320
50	9460	9440	9420	9399	9378	9356	9335	9313	9290	9267	9244	9221
55	9368	9347	9325	9302	9279	9256	9234	9211	9187	9163	9139	9114
60	9267	9245	9222	9198	9174	9150	9126	9102	9076	9051	9026	9000
65	9162	9138	9113	9088	9063	9038	9013	8988	8962	8936	8909	8882
70	9046	9021	8996	8970	8944	8917	8892	8866	8839	8812	8784	8756
75	8925	8890	8873	8847	8820	8792	8765	8738	8710	8681	8652	8622
80	8798	8771	8744	8716	8688	8659	8631	8602	8573	8544	8514	8483
85	8663	8635	8606	8577	8547	8517	8488	8458	8427	8396	8365	8333
90	8517	8486	8455	8425	8395	8363	8332	8300	8268	8236	8204	8171

TRALLES' TABLE VI.

To be added.						To be subtracted.					
30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°
·0005	·0004	·0003	·0002	·0002	·0001	—	·0001	·0002	·0002	·0003	·0004

For the reasons assigned under Tables III. and IV., the numbers in Table VI. must be added or subtracted, as may be deemed necessary, to or from the specific gravities given in Table V., according to the temperature.

From the above tables, the true amount of alcohol in a liquor, or "its richness," may be ascertained by the specific gravity.

It will be as well to consider here the method used for ascertaining the specific gravity of the various liquids. The density is invariably found by one of two methods—either by actually weighing a portion of the liquor in an accurate specific gravity bottle, or by hydrometer.

The latter mode is generally adopted, being more expeditious in practice. Various hydrometers are employed, the principal ones being Beaumé's, Sikes', and Dicas', all of which have corresponding tables to indicate the quantities of alcohol according to the gravity. It being thought more convenient and simple to have an instrument which would indicate at once the amount of alcohol, one was formed, partly on the plan of the hydrometer, to which the term *alcoholometer* has been applied; it may be made either of glass or brass. TRALLES, in constructing one of these instruments, has drawn up the annexed alcoholometric table for guidance, which shows, from the portion of the stem immersed in the liquor, the amount of alcohol contained at 60° Fahr.

TRALLES' TABLE VII.

Per cent. alcohol, by volume.	Length of immersed part of stem.	Distance between degrees of scale indicating per cent.	Per cent. alcohol, by volume.	Length of immersed part of stem.	Distance between degrees of scale indicating per cent.
0	9		51	735	23
1	24	15	52	758	23
2	39	15	53	782	24
3	54	15	54	806	24
4	68	14	55	830	24
5	82	14	56	854	24
6	95	13	57	879	25
7	108	13	58	905	26
8	121	13	59	931	26
9	133	12	60	957	26
10	145	12	61	984	27
11	157	12	62	1011	27
12	169	12	63	1039	28
13	180	11	64	1067	28
14	191	11	65	1096	29
15	202	11	66	1125	29
16	213	11	67	1154	29
17	224	11	68	1184	30
18	235	11	69	1215	31
19	245	10	70	1246	31
20	256	10	71	1278	32
21	266	10	72	1310	32
22	277	11	73	1342	32
23	288	11	74	1375	33
24	299	11	75	1409	34
25	310	11	76	1443	34
26	321	11	77	1478	35
27	332	11	78	1514	36
28	344	12	79	1550	36
29	355	11	80	1587	37
30	367	12	81	1624	37
31	380	13	82	1662	38
32	393	13	83	1701	39
33	407	14	84	1740	39
34	420	13	85	1781	41
35	434	14	86	1823	42
36	449	15	87	1866	43
37	465	16	88	1910	44
38	481	16	89	1955	45
39	498	17	90	2002	47
40	515	17	91	2050	48
41	533	18	92	2099	49
42	551	18	93	2150	51
43	569	18	94	2203	53
44	588	19	95	2259	56
45	608	20	96	2318	59
46	628	20	97	2380	62
47	648	20	98	2447	67
48	669	21	99	2519	72
49	690	21	100	2597	78
50	712	22			

In the practical application of the preceding table, when graduating the alcoholometer, it is requisite to have two liquids of a standard strength and temperature.

Distilled water may be one of these, and the other any alcoholic liquor, the percentage of which has been precisely determined, but it is necessary that both should be at 60° Fahr. The level at which the instrument stands in each should be scratched on the stem, and the intermediate space accurately divided according to the strength of the liquid. If the alcoholic liquor be 49 per cent., and the difference between the point to which the instrument sinks in this liquid and water be divided into 690 — 9 = 681 equal parts, the addition of 22 such parts will indicate the point for 50 per cent., and 23 more for 51 per cent., and so on, as is seen in the third column in the table. By adding 9 such divisions below zero, or the water-level mark, the point is attained from which the numbers in the second column in the table are calculated for each succeeding per cent. of spirit.

In graduating the scale, it would perhaps be more convenient to have two instruments; one to have indications denoting a percentage, say from 1 to 80, and the other from the latter up to pure alcohol. For this end it would, however, be absolutely necessary to adjust the instrument having the higher indications, with two liquids at the normal degree of temperature of the preceding, whose percentage of alcohol should be 80 and 100; then, to observe the points to which it sinks in these, and divide the intermediate space into measures corresponding with those in the table.

In constructing this alcoholometer it is essential that its stem should for ordinary purposes be as uniform as possible. Tubes which do not vary throughout their length more than one-thirtieth of their diameter, may be safely used.

The temperature of the liquid must be at 60° Fahr., or else the true percentage must be calculated from this gravity in the usual way, by the preceding Tables III. or IV.

To dispense with the trouble of such a calculation, TRALLES devised another table, by which the real percentage of alcohol is found in liquids of different temperatures, from the results exhibited by the instrument. This table is given below, Table VIII., and corresponds with the preceding Table III.

The numbers in the vertical columns under the temperatures, are the observed degrees of the alcoholometer, and indicate the percentage of the absolute alcohol by volume. If an alcoholic liquid at a temperature of 75° Fahr. be found to contain 62·9 per cent. by volume, by reference to the table its true percentage at 60° Fahr. is 60.

Tables IX. and X. following give the richness per cent. by volume of the liquid at the temperature it possesses when tested. They correspond with Table V., and like it require that the solution should be tested at exactly the same temperature at which it is measured. Table IX. is for a glass, and Table X. for a brass alcoholometer.

TRALLES' TABLE VIII.

To find the true percentage of absolute alcohol by volume, in a liquid at 60° Fahr. from the observed percentage indicated by a glass alcoholometer at any other temperature (degrees Fahr.).

30°	35°	40°	45°	50°	55°	60°	60°	65°	70°	75°	80°	85°
— 0·2	— 0·4	— 0·4	— 0·5	— 0·4	— 0·2	0	0	+ 0·2	+ 0·6	+ 1·0	+ 1·4	+ 1·9
+ 4·6	+ 4·5	+ 4·5	+ 4·5	+ 4·6	+ 4·8	5	5	5·3	5·8	6·2	6·7	7·3
9·1	9·0	9·1	9·2	9·3	9·7	10	10	10·4	11·0	11·6	12·3	13·0
13·0	13·1	13·3	13·5	13·9	14·5	15	15	15·6	16·3	17·1	18·0	19·0
16·5	16·9	17·4	17·8	18·5	19·2	20	20	20·8	21·8	22·8	23·8	24·9
19·9	20·6	21·4	22.2	23·0	24·1	25	25	25·9	27·0	28·2	29·4	30·5
23·5	24·5	25·7	26·6	27·7	28·8	30	30	31·1	32·2	33·4	34·5	35·7
28·0	29·2	30·4	31·6	32·7	33·8	35	35	36·2	37·3	38·4	39·5	40·6
33·0	34·2	35·4	36·7	37·8	39·0	40	40	41·1	42·2	43·3	44·3	45·4
38·4	39·6	40·7	41·8	42·9	43·9	45	45	46·1	47·1	48·2	49·2	50·3
43·7	44·7	45·8	46·9	47·9	49·0	50	50	51·0	52·0	53·0	54·0	55·1
49·0	50·0	51·0	52·0	53·0	54·0	55	55	54·9	56·9	57·9	58·9	59·9
54·2	55·2	56·2	57·1	58·1	59·0	60	60	60·9	61·9	62·9	63·8	64·9
59·4	60·3	61·2	62·2	63·1	64·0	65	65	65·9	66·8	67·7	68·6	69·6
64·6	65·5	66·4	67·3	68·2	69·1	70	70	70·8	71·7	72·6	73·5	74·5
69·8	70·7	71·5	72·4	73·3	74·2	75	75	75·8	76·7	77·6	78·4	79·3
75·0	75·8	76·6	77·5	78·4	79·2	80	80	80·8	81·7	82·4	83·2	84·1
80·3	81·1	81·8	82·6	83·5	84·3	85	85	85·7	86·5	87·3	88·0	88·8
85·6	86·4	87·1	87·9	88·6	89·3	90	90	90·7	91·4	92·0	92·7	93·4

TRALLES' TABLE IX.

To find the true percentage of absolute alcohol by volume, in a liquid of any temperature, from the observed per centage indicated by the glass alcoholometer at the same temperature.

True per cent. of alcohol by volume, at Fahr.	Observed per cent. indicated by the glass alcoholometer.										
	30°	35°	40°	45°	50°	55°	65°	70°	75°	80°	85°
0	— 0·2	— 0·4	— 0·4	— 0·5	— 0·4	— 0·2	+ 0·2	+ 0·6	+ 1·0	+ 1·4	+ 1·9
5	+ 4·6	+ 4·5	+ 4·5	+ 4·5	+ 4·6	+ 4·8	5·3	5·8	6·2	6·7	7·3
10	9·1	9·0	9·1	9·2	9·3	9·7	10·4	11·0	11·6	12·3	13·0
15	13·0	13·1	13·3	13·6	14·1	14·5	15·6	16·3	17·1	18·0	19·0
20	16·5	16·9	17·4	17·9	18·5	19·2	20·8	21·8	22·9	23·9	25·0
25	19·8	20·5	21·3	22·2	23·0	24·1	25·9	27·1	28·3	29·5	30·7
30	23·3	24·3	25·5	26·5	27·6	28·8	31·2	32·3	33·5	34·6	35·9
35	27·7	28·9	30·2	31·4	32·6	33·8	36·3	37·5	38·6	39·7	40·9
40	32·5	33·8	35·1	36·5	37·7	38·9	41·2	42·4	43·5	44·6	45·8
45	37·8	39·1	40·3	41·5	42·7	43·8	46·2	47·3	48·5	49·6	50·8
50	43·1	44·2	45·4	46·6	47·7	48·9	51·1	52·2	53·4	54·5	55·6
55	48·3	49·4	50·5	51·6	52·8	53·9	56·1	57·2	58·3	59·4	60·5
60	53·4	54·5	55·6	56·7	57·8	58·9	61·1	62·2	63·3	64·4	65·5
65	58·4	59·5	60·6	61·7	62·8	63·9	66·0	67·1	68·2	69·3	70·4
70	63·5	64·6	65·7	66·8	67·9	69·0	71·0	72·1	73·2	74·3	75·4
75	68·6	69·7	70·7	71·8	72·9	74·0	76·0	77·1	78·2	79·2	80·3
80	73·7	74·8	75·8	76·9	78·0	79·0	81·0	82·1	83·1	84·1	85·2
85	78·8	79·8	80·9	81·9	83·0	84·0	86·0	87·0	88·0	89·0	90·0
90	84·0	85·1	86·1	87·1	88·1	89.1	91·0	91·9	92·8	93·7	94·6

Thus, if the alcoholometer indicated 59·4 per cent. in a liquid at 80°, the table would give its true percentage as 55 per cent., that is, 100 volumes of the liquid at 80° contain 55 volumes of anhydrous alcohol.

TRALLES' TABLE X.

To find the true percentage of absolute alcohol in a liquid of any temperature, from the observed percentage indicated by a brass alcoholometer at the same temperature.

True per cent. of alcohol by volume.	Observed per cent. indicated by the brass alcoholometer.										
	30°	35°	40°	45°	50°	55°	65°	70°	75°	80°	85°
0	— 0·1	— 0·1	— 0·2	— 0·3	— 0·3	— ·0·2	+ 0·2	+ 0·5	+ 0·9	+ 1·2	+ 1·7
5	+ 5·0	+ 4·8	+ 4·7	+ 4·8	+ 4·7	+ 4·8	5·2	5·6	6·1	6·5	7·0
10	9·5	9·4	9·4	9·4	9·5	9·7	10·3	10·8	11·4	12·0	12·6
15	13·5	13·5	13·6	13·7	14·0	14·6	15·5	16·2	17·0	17·7	18·6
20	17·0	17·3	17·7	18·1	18·7	19·3	20·7	21·6	22·7	23·7	24·0
25	20·3	20·9	21·6	22·4	23·3	24·2	25·8	26·9	28·1	29·2	30·3
30	23·8	24·7	25·8	26·8	27·8	28·9	31·1	32·2	33·3	34·4	35·5
35	28·2	29·3	30·4	31·6	32·8	33·9	36·2	37·3	38·4	39·5	40·7
40	32·9	34·1	35·4	36·7	37·9	39·0	41·1	42·2	43·4	44·5	45·6
45	38·1	39·3	40·4	41·6	42·7	43·9	46·1	47·2	48·3	49·4	50·5
50	43·4	44·5	45·6	46·7	47·8	48·9	51·1	52·2	53·3	54·4	55·5
55	48·5	49·6	50·7	51·8	52·9	54·0	56·0	57·1	58·2	59·3	60·4
60	53·6	54·6	55·7	56·8	57·8	58·9	61·0	62·1	63·2	64·3	65·3
65	58·6	59·7	60·7	61·8	62·8	63·9	66·0	67·1	68·1	69·2	70·2
70	63·7	64·8	65·8	66·9	67·9	69·0	71·0	72·1	73·1	74·2	75·2
75	68·8	69·8	70·9	71·9	72·9	74·0	76·0	77·0	78·1	79·1	80·1
80	73·9	74·9	75·9	76·9	78·0	79·0	81·0	82·0	83·0	84·0	85·0
85	79·0	80·0	81·0	82·0	83·0	84·0	86·0	87·0	88·0	88·9	89·9
90	84·2	85·3	86·2	87·2	88·1	89.1	90·9	91·9	92·8	93·7	94·5

The preceding ten tables of Tralles contain all that is requisite for the determination of the volume of alcohol in a liquid; they have been constructed on the principle of the tables of Gilpin. Tralles experiments were made in 1811, he found that Gilpin's alcohol, so far from being absolute, contained 10·8 per cent. of water. Since then further extensive researches have been made by many eminent chemists, the most important being those of Gay-Lussac, who in 1824 drew up much more extensive tables, which require scarcely any interpolation.

Gay-Lussac's instrument is like a glass hydrometer, the stem of which is divided into degrees like that of Tralles, to indicate the percentage of alcohol by volume, but the temperature at which the graduation was made was 15° C. or 59° Fahr., instead of 60° Fahr., as the normal temperature of Tralles' tables. Water is taken as unity at this temperature. The stem of the instrument is divided, from the point at which it stands in water, into 100 divisions, so that each on the scale is equal to one per cent. of alcohol; the 100th division indicates pure or absolute alcohol, while 0 or zero equals pure water at 15 C.

The instrument, if immersed in an alcoholic liquor at 59° Fahr., marks the strength by the number of degrees below the surface; thus, if the alcoholometer stands at 57 in a liquid at 59°, such a solution contains 57 per cent. by volume of alcohol.

In consequence of the temperature 59° Fahr. (15° C.) being taken by Gay-Lussac, as the fundamental numbers for determining the relation, the percentage of alcohol and the specific gravities are in a slight degree different from those of Tralles, but the variation is so minute that in practice it may be overlooked.

In the annexed table the fundamental numbers of the centesimal amount per volume, together with the specific gravities of the different alcoholic mixtures at 59° Fahr. (15° C.), are given:—

Per cent. of alcohol by volume.	Specific gravity of the liquid at 59°.	Per cent. of alcohol by volume.	Specific gravity of the liquid at 59°.
100	0·7947	60	0·9141
95	0·8168	55	0·9248
90	0·8346	50	0·9348
85	0·8502	45	0·9440
80	0·8645	40	0·9523
75	0·8799	35	0·9595
70	0·8907	10	0·9656
65	0·9027	0	1·0000

The first table by Gay-Lussac is denominated *Table for the* real *strength of spirits*, and corresponds with Table VIII. of Tralles. This table gives the true percentage by volume at 59° Fahr. (15° C.) from the observed percentage of the alcoholometer at any other temperature. Two numbers are placed in the same horizontal column, and vertical to each other: those in the top are the observed centesimal quantities of the alcoholometer, while the large figures in the vertical column below them give the real percentages at 59° Fahr. when tested at the temperature found in the left-hand vertical column. The numbers in small figures beneath the real percentages denote the bulk at 59° Fahr. (15° C.) of 1000 measures of liquid; this number, multiplied by the real percentage under which it stands, gives the absolute quantity of alcohol at the temperature at which the experiment is performed.

To read the table, suppose an alcoholic liquid of 50 strength indicated by the alcoholometer at a temperature of 68° Fahr., the observed percentage—50—is sought in the horizontal column at the top; in the vertical column beneath this and on a line with 68°, in the temperature column at the left hand, will be found the number 48·2, which is the quantity of *real* spirit at 59°. The number 996, in small figures below the indicated strength at 59°, is the bulk or volume which 1000 volumes would occupy at the standard temperature; and by multiplying this number by the proper strength, and dividing the product by 1000, the strength or true volume of spirit in 1000 of the liquid is ascertained; thus—

996 + 48·2 = 48007·2 + 1000 = 48·00, the percentage;

hence, 100 volumes of the liquor at 58° contain 48 volumes of absolute alcohol at 59°.

Morazeau constructed, with one of Gay-Lussac's alcoholometers, a table somewhat more in detail, which differs slightly from the preceding in the figures denoting the density, although they have reference to the same temperature.

When, however, the liquors to be tested stand at a higher degree than 59° Fahr. (15° C.), no provision is made to discover the true amount of spirit, which must then be sought either by other tables or by the calculation given earlier.

Per cent. of alcohol by volume.	Specific gravity.	Per cent. of alcohol by volume.	Specific gravity.	Per cent. of alcohol by volume.	Specific gravity.
0	1·000	34	0·962	68	0·896
1	0·999	35	0·960	69	0·893
2	0·997	36	0·959	70	0·891
3	0·996	37	0·957	71	0·888
4	0·994	38	0·956	72	0·884
5	0·993	39	0·954	73	0·881
6	0·992	40	0·953	74	0·879
7	0·990	41	0·951	75	0·876
8	0·989	42	0·949	76	0·874
9	0·988	43	0·948	77	0·871
10	0·987	44	0·946	78	0·868
11	0·986	45	0·945	79	0·865
12	0·984	46	0·943	80	0·863
13	0·983	47	0·941	81	0·860
14	0·982	48	0·940	82	0·857
15	0·981	49	0·938	83	0·854
16	0·980	50	0·936	84	0·851
17	0·979	51	0·934	85	0·848
18	0·978	52	0·932	86	0·845
19	0·977	53	0·930	87	0·842
20	0·976	54	0·928	88	0·838
21	0·975	55	0·926	89	0·835
22	0·974	56	0·924	90	0·832
23	0·973	57	0·922	91	0·829
24	0·972	58	0·920	92	0·826
25	0·971	59	0·918	93	0·822
26	0·970	60	0·915	94	0·818
27	0·969	61	0·913	95	0·814
28	0·968	62	0·911	96	0·810
29	0·967	63	0·909	97	0·805
30	0·966	64	0·906	98	0·800
31	0·965	65	0·904	99	0·795
32	0·964	66	0·902	100	0·747
33	0·963	67	0·899		

(GAY-LUSSAC).—ALCOHOLOMETRIC TABLE I.

To find the per cent., by volume, in a liquid at 59° from the observed per cent. at any other temperature.
The temperature Centigrade is below that of Fahrenheit.

Temp. Fahr.	Observed per centage of the Alcoholometer.									
	1 p.cent.	2 p cent.	3 p.cent.	4 p.cent.	5 p.cent.	6 p.cent.	7 p.cent.	8 p.cent.	9 p.cent.	10 p.cent
32·0° 0° C.	1·3 1000	2·4 1000	3·4 1000	4·4 1000	5·4 1000	6·5 1001	7·5 1001	8·6 1001	9·7 1001	10·9 1001
33·8 1 C.										
35·6 2 C.										
37·4 3 C.										
39·2 4 C.										
41·0 5 C.	1·4 1001	2·5 1001	3·5 1001	4·5 1001	5·5 1001	6·6 1001	7·7 1001	8·7 1001	9·8 1001	10·9 1001
42·8 6 C.										
44·6 7 C.										
46·4 8 C.										
48·2 9 C.										
50·0 10 C.	1·4 1000	2·4 1000	3·4 1001	4·5 1001	5·5 1001	6·5 1001	7·5 1001	8·5 1001	9·5 1001	10·6 1001
51·8 11 C.	1·3 1000	2·4 1000	3·4 1000	4·4 1001	5·4 1001	6·4 1001	7·4 1001	8·4 1001	9·4 1001	10·5 1001
53·6 12 C.	1·2 1000	2·3 1000	3·3 1000	4·3 1000	5·3 1000	6·3 1000	7·3 1000	8·3 1000	9·3 1000	10·4 1000
55·4 13 C.	1·2 1000	2·2 1000	3·2 1000	4·2 1000	5·2 1000	6·2 1000	7·2 1000	8·2 1000	9·2 1000	10·3 1000
57·2 14 C.	1·1 1000	2·1 1000	3·1 1000	4.1 1000	5·1 1000	6·1 1000	7·1 1000	8·1 1000	9·1 1000	10·2 1000
59·0 15 C.	1 1000	2 1000	3 1000	4 1000	5 1000	6 1000	7 1000	8 1000	9 1000	10 1000
60·8 16 C.	0·9 1000	1·9 1000	2·9 1000	3·9 1000	4·9 1000	5·9 1000	6·9 1000	7·9 1000	8·9 1000	9·9 1000
62·6 17 C.	0·8 1000	1·8 1000	2·8 1000	3·8 1000	4·8 1000	5·8 1000	6·8 1000	7·8 1000	8·8 1000	9·8 1000
64·4 18 C.	0·7 1000	1·7 1000	2·7 1000	3·7 1000	4·7 1000	5·7 1000	6·7 1000	7·7 1000	8·7 1000	9·7 1000
66·2 19 C.	0·6 999	1·6 999	2·6 999	3·5 999	4·5 999	5·5 999	6·5 999	7·5 999	8·5 999	9·5 999
68·0 20 C.	0·5 999	1·5 999	2·4 999	3·4 999	4·4 999	5·4 999	6·4 699	7·3 999	8·3 999	9·3 999
69·8 21 C.	0·4 999	1·4 999	2·3 999	3·3 999	4·3 999	5·2 999	6·2 999	7·1 999	8·1 999	9·1 999
71·6 22 C.	0·3 999	1·3 999	2·2 999	3·2 999	4·1 999	5·1 999	6·1 999	7 999	7·9 999	8·9 999
73·4 23 C.	0·1 999	1·1 999	2·1 999	3·1 999	4 999	4·9 599	5·9 999	6·8 998	7·8 998	8·7 998
75·2 24 C.		1 998	1·9 998	2·9 998	3·8 998	4·8 998	5·8 998	6·7 998	7·6 998	8·5 998
77·0 25 C.		0·8 998	1·7 998	2·7 998	3·6 998	4·6 998	5·5 998	6·5 998	7·4 998	8·3 998
78·8 26 C.		0·7 998	1·6 998	2·6 998	3·5 998	4·4 998	5·4 998	6·3 998	7·2 998	8·1 998
80·6 27 C.		0·5 998	1·5 998	2·4 998	3·3 998	4·3 998	5·2 998	6·1 998	7 998	7·9 998
82·4 28 C.		0·3 997	1·3 997	2·2 997	3·1 997	4·1 997	5 997	5·9 497	6·8 997	7·7 997
84·2 29 C.		0·1 997	1·1 997	2 997	2·9 997	3·9 997	4·8 997	5·7 997	6·6 997	7·5 697
86·0 30 C.		0·0 997	0·9 997	1·9 997	2·8 997	3·7 997	4·6 997	5·5 997	6·4 997	7·3 997

Temp. Fahr.	Observed per centage of the Alcoholometer.									
	11 p.cent.	12 p.cent.	13 p.cent.	14 p.cent.	15 p.cent.	16 p.cent.	17 p.cent.	18 p.cent.	19 p.cent.	20 p.cent.
32·0° 0° C.	12·2 1001	13·4 1002	14·7 1002	16·1 1002	17·5 1002	18·9 1003	20·3 1003	21·6 1004	22·9 1004	24·2 1004
33·8 1 C.		13·4 1002	14·7 1002	16 1002	17·3 1002	18·7 1003	20 1003	21·3 1003	22·6 1004	23·9 1004
35·6 2 C.		13·4 1002	14·7 1002	16 1002	17·2 1002	18·5 1003	19·8 1003	21·1 1003	22·3 1004	23·6 1004
37·4 3 C.		13·3 1001	14·6 1002	15·9 1002	17·1 1002	18·3 1002	19·6 1003	20·8 1003	22 1003	23·3 1004
39·2 4 C.		13·3 1001	14·5 1002	15·8 1002	16·9 1002	18·1 1002	19·4 1002	20·6 1003	21·8 1003	23 1003
41·0 5 C.	12·1 1001	13·2 1001	14·4 1001	15·7 1002	16·8 1002	18 1002	19·2 1002	20·4 1003	21·5 1003	22·7 1003
42·8 6 C.		13·1 1001	14·3 1001	15·6 1002	16·7 1002	17·8 1002	19 1002	20·2 1003	21·3 1003	22·4 1003
44·6 7 C.		13 1001	14·2 1001	15·4 1001	16·6 1002	17·7 1002	18·8 1002	20 1002	21 1002	22·1 1002
46·4 8 C.		13 1001	14·1 1001	15·3 1001	16·4 1001	17·5 1001	18·6 1002	19·7 1002	20·7 1002	21·8 1002
48·2 9 C.		12·9 1001	14 1001	15·1 1001	16·2 1001	17·3 1001	18·4 1001	19·5 1001	20 5 1002	21·6 1002
50·0 10 C.	11·7 1001	12·7 1001	13·8 1001	14·9 1001	16 1001	17 1001	18·1 1001	19·2 1001	20·2 1001	21·3 1001
51·8 11 C.	11·6 1001	12·6 1001	13·6 1001	14·7 1001	15·8 1001	16·8 1001	17·9 1001	19 1001	20 1001	21 1001
53·6 12 C.	11·5 1000	12·5 1001	13·5 1001	14·6 1001	15·6 1001	16·6 1001	17·6 1001	18·7 1001	19·7 1001	20·7 1001
55·4 13 C.	11·4 1000	12·4 1000	13·4 1000	14·4 1000	15·4 1000	16·4 1000	17·4 1000	18·5 1000	19·5 1000	20·5 1000
57·2 14 C.	11·2 1000	12·2 1000	13·2 1000	14·2 1000	15·2 1000	16·2 1000	17·2 1000	18·2 1000	19·2 1000	20·2 1000
59·0 15 C.	11 1000	12 1000	13 1000	14 1000	15 1000	16 1000	17 1000	18 1000	19 1000	20 1000
60·8 16 C.	10·9 1000	11·9 1000	12·9 1000	13·9 1000	14·9 1000	15·9 1000	16·9 1000	17·8 1000	18·7 1000	19·7 1000
62·6 17 C.	10·8 1000	11·7 1000	12·7 1000	13·7 1000	14·7 1000	15·6 1000	16·6 1000	17·5 1000	18·4 999	19·4 999
64·4 18 C.	10·7 1000	11·6 1000	12·5 999	13·5 999	14·5 999	15·4 999	16·3 999	17·3 999	18·2 999	19·1 999
66·2 19 C.	10·5 999	11·4 999	12·4 999	13·3 999	14·3 999	15·2 999	16·1 999	17 999	17·9 999	18·8 999
68·0 20 C.	10·3 999	11·2 999	12·2 999	13·1 999	14 999	14·9 999	15·8 999	16·7 999	17·6 999	18·5 999
69·8 21 C.	10·1 999	11 999	11·9 999	12·8 999	13·7 999	14·6 999	15·5 998	16·4 998	17·3 998	18·2 998
71·6 22 C.	9·9 999	10·8 999	11·7 999	12·6 998	13·5 998	14·4 998	15·3 998	16·2 998	17 998	17·9 998
73·4 23 C.	9·7 998	10·6 998	11·5 998	12·4 998	13·3 998	14·1 998	15 998	15·9 998	16·7 998	17·6 998
75·2 24 C.	9·5 998	10·4 998	11·3 998	12·2 998	13·1 998	13·9 998	14·8 998	15·7 998	16·5 997	17·4 997
77·0 25 C.	9·3 998	10·2 998	11·1 998	12 998	12·8 998	13·6 998	14·5 997	15·4 997	16·2 997	17·1 997
78·8 26 C.	9 998	9·9 997	10·8 997	11·7 997	12·6 997	13·4 997	14·2 997	15·1 997	15·9 997	16·8 997
80·6 27 C.	8·8 997	9·7 997	10·6 997	11·5 997	12·3 997	13·1 997	14 997	14·8 997	15·6 997	16·5 997
82·4 28 C.	8·6 997	9·5 997	10·3 997	11·2 997	12 967	12·8 996	13·7 996	14·5 996	15·3 996	16·1 996
84·2 29 C.	8·4 997	9·2 997	10·1 997	11 997	11·8 996	12·6 996	13·4 996	14·2 996	15 996	15·8 996
86·0 30 C.	8·1 997	9 996	9·8 996	10·7 996	11·5 996	12·3 996	13·1 996	13·9 996	14·7 996	15·5 996

(GAY-LUSSAC).—TABLE I.—Continued.

Temp. Fahr.	Observed per centage of the Alcoholometer.										Temp. Fahr.	Observed per centage of the Alcoholometer.									
	21 p.cent.	22 p.cent.	23 p.cent.	24 p.cent.	25 p.cent.	26 p.cent	27 p.cent.	28 p.cent.	29 p cent	30 p.cent.		31 p cent.	32 p cent.	33 p.cent.	34 p.cent.	35 p.cent.	36 p.cent.	37 p.cent.	38 p.cent.	39 p.cent.	40 p.cent.
32·0° 0° C.	25.6 1005	27 1005	28·4 1006	29·7 1006	30·9 1007	32·1 1007	33·2 1007	34·3 1008	35·3 1008	36·3 1008	32·0° 0° C.	37·3 1009	38·3 1009	39·2 1009	40·2 1009	41·1 1009	42·1 1010	43·1 1010	44 1010	45 1010	45·9 1011
33·8 1 C.	25·3 1005	26·7 1005	28 1005	29·2 1006	30·4 1006	31·6 1006	32·7 1007	33·8 1007	34·8 1007	35·8 1008	33·8 1 C.	36·8 1008	37·8 1008	38·8 1008	39·8 1008	40·8 1009	41·8 1009	42·7 1009	43·7 1009	44·6 1010	45 5 1010
35·6 2 C.	24·9 1004	26·3 1005	27·5 1005	28·8 1005	30 1006	31·2 1006	32·3 1006	33·3 1006	34·4 1007	35·4 1007	35·6 2 C.	36·4 1007	37·4 1007	38·4 1008	39·4 1008	40·4 1008	41·4 1008	42·3 1008	43·3 1009	44·2 1009	45·1 1009
37·4 8 C.	24·6 1004	25·9 1005	27·1 1005	28·4 1005	29·6 1005	30·8 1006	31·9 1006	32·9 1006	33·9 1007	34·9 1007	37·4 3 C.	36 1007	37 1007	38 1007	39 1007	40 1007	41 1008	42 1008	42·9 1008	43·9 1008	44·8 1008
39·2 4 C.	24·3 1004	25·6 1004	26 8 1005	28 1005	29·2 1005	30·4 1005	31·4 1005	32·5 1005	33 5 1006	34·5 1006	39·2 4 C.	35·5 1006	36·5 1006	37·5 1006	38·5 1007	39·5 1007	40·5 1007	41·5 1007	42·5 1007	43·5 1007	44·4 1008
41·0 5 C.	24 1003	25·2 1003	26·4 1004	27·6 1004	28·8 1004	30 1004	31 1005	32·1 1005	33·1 1005	34·1 1005	41·0 5 C	35·1 1005	36·1 1006	37·1 1006	38·1 1006	39·1 1006	40·1 1006	41·1 1007	42·1 1007	43·1 1007	44 1007
42·8 6 C.	23·6 1003	24·9 1003	26 1004	27·2 1004	28·4 1004	29·6 1004	30·6 1005	31·6 1005	32·6 1005	33·6 1005	42·8 6 C	34·7 1005	35·7 1005	36·7 1005	37·7 1005	38·7 1005	39·7 1006	40·7 1006	41 1006	42·6 1006	43·6 1006
44·6 7 C.	23·3 1002	24·6 1003	25·7 1003	26·9 1003	28 1003	29·2 1003	30·2 1004	31.2 1004	32·2 1004	33·2 1004	44·6 7 C.	34·2 1004	35·2 1004	36·2 1004	37·2 1005	38·2 1005	39·2 1005	40·2 1005	41·2 1005	42·2 1005	43·2 1005
46·4 8 C.	23 1002	24·2 1002	25·3 1003	26·5 1003	27·6 1003	28·8 1003	29·8 1003	30·8 1003	31·8 1003	32·8 1003	46·4 8 C	33·8 1004	34·8 1004	35·8 1004	36·8 1004	37·8 1004	38·8 1004	39·8 1004	40·8 1004	41·8 1004	42·8 1005
48·2 9 C.	22·7 1002	23·9 1002	25 1002	26·1 1002	27·2 1002	28·4 1003	29·4 1003	30 4 1003	31·4 1003	32·4 1003	48·2 9 C.	33·4 1003	34·4 1003	35·4 1003	36·4 1003	37·4 1004	38·4 1004	39·4 1004	40 4 1004	41·4 1004	42·4 1004
50·0 10 C.	22·4 1001	23·5 1002	24·6 1002	25·7 1002	26·8 1002	27·9 1002	29 1002	30 1002	31 1002	32 1002	50·0 10 C.	33 1002	34 1002	35 1003	36 1003	37 1003	38 1003	39 1003	40 1003	41 1003	42 1003
51·8 11 C.	22·1 1001	23·2 1001	24·3 1001	25·4 1001	26·5 1002	27·6 1002	28·6 1002	29·6 1002	30·6 1002	31·6 1002	51·8 11 C.	32·6 1002	33·6 1002	34·6 1002	35·6 1002	36·6 1002	37·6 1002	38·6 1002	39·6 1002	40·6 1003	41·6 1003
53·6 12 C.	21·8 1001	22·9 1001	24 1001	25·1 1001	26·1 1001	27·2 1001	28·2 1001	29·2 1001	30·2 1001	31·2 1001	53·6 12 C.	32·2 1001	33·2 1001	34·2 1002	35·2 1002	36·2 1002	37·2 1002	38·2 1002	39·2 1002	40·2 1002	41·2 1002
55·4 13 C.	21·5 1001	22·6 1001	23·6 1001	24·7 1001	25·7 1001	26·8 1001	27·8 1001	28·8 1001	29·8 1001	30·8 1001	55·4 13 C.	31·8 1001	32·8 1001	33·8 1001	34·8 1001	35·8 1001	36·8 1001	37·8 1001	38·8 1001	39·8 1001	40·8 1001
57·2 14 C.	21 2 1000	22·3 1000	23·3 1000	24·3 1000	25·3 1000	26·4 1000	27·4 1000	28·4 1000	29·4 1000	30·4 1000	57·2 14 C.	31·4 1000	32·4 1000	33·4 1001	34·4 1001	35·4 1001	36·4 1001	37·4 1001	38·4 1001	39·4 1001	40·4 1001
59·0 15 C	21 1001	22 1000	23 1000	24 1000	25 1000	26 1000	27 1000	28 1000	29 1000	30 1000	59·0 15 C	31 1000	32 1000	33 1000	34 1000	35 1000	36 1000	37 1000	38 1000	39 1000	40 1000
60·8 16 C.	20·7 1000	21·7 1000	22·7 1000	23·7 1000	24·7 1000	25·7 1000	26·6 1000	27·6 1000	28·6 1000	29·6 1000	60·8 16 C.	30·6 1000	31·6 1000	32.5 999	33·5 999	34·5 999	35·5 999	36·5 999	37·5 999	38·5 999	39·5 999
62·6 17 C.	20·4 999	21·4 999	22·4 999	23·4 999	24·4 999	25·4 999	26·3 999	27·3 999	28·2 999	29·2 999	62·6 17 C.	30·2 999	31·2 999	32·1 999	33·1 999	34·1 999	35·1 999	36·1 999	37 1 999	38·1 999	39·1 999
64·4 18 C.	20·1 999	21·1 999	22 999	23 999	24 999	25 999	25·9 999	26·9 999	27·8 999	28·8 999	64·4 18 C	29·8 999	30·8 999	31·7 998	32·7 998	33·7 998	34·7 998	35 7 998	36·7 998	37·7 998	38·7 998
66·2 19 C.	19·8 999	20·8 999	21·7 999	22·7 999	23·6 998	24·6 998	25·5 998	26·5 998	27·4 998	28·4 998	66·2 19 C.	29·4 998	30·4 998	31·3 998	32·3 998	33·3 998	34 3 998	35·3 998	36·3 998	37·3 997	38·3 997
68·0 20 C.	19·5 999	20·5 998	21·4 998	22·4 998	23·3 998	24·3 998	25·2 998	26 1 998	27·1 998	28 998	68·0 20 C	29 998	30 998	30·9 997	31·9 997	32·9 997	33·9 997	34·9 997	35·9 997	36·9 997	37·9 997
69·8 21 C.	19·1 998	20·1 998	21.1 998	22·1 998	23 998	23·9 998	24·8 998	25·7 998	26·7 997	27·6 997	69·8 21 C.	28·6 997	29·6 997	30 5 997	31·5 997	32·5 997	33·5 997	34·5 997	35·5 996	36·5 996	37·5 996
71·6 22 C.	18·8 998	19·8 998	20·7 998	21·7 997	22·6 997	23·6 997	24·4 997	25·3 997	26·3 997	27·2 997	71·6 22 C	28·2 997	29·2 997	30·1 996	31·1 996	32·1 996	33·1 996	34·1 996	35·1 996	36·1 996	37·1 996
73·4 23 C.	18·5 998	19·5 997	20·4 997	21 4 997	22·3 997	23 2 997	24·1 997	25 997	25·9 997	26·8 997	73·4 23 C.	27·8 996	28·8 996	29·7 996	30·7 996	31·7 996	32·7 996	33·7 896	34·7 995	35·7 995	36·7 995
75·2 24 C.	18·3 997	19·2 997	20·1 997	21·1 997	21·9 997	22·8 997	23·7 997	24·6 996	25·5 996	26·4 996	75·2 24 C.	27·4 996	28·4 996	29·3 995	30·3 995	31·3 995	32·3 995	33·3 995	34·3 995	35·3 995	36·3 994
77·0 25 C.	18 997	18·9 997	19·8 997	20·7 997	21·6 996	22·5 996	23·3 996	24·3 996	25·2 995	26·1 996	77·0 25 C.	27 995	28 995	28·9 995	29·9 995	30·9 995	31·9 994	32·9 994	33·9 994	34·9 994	35·9 994
78·8 26 C.	17·7 997	18·6 996	19·5 996	20·4 996	21·3 996	22·2 996	23 996	23·9 996	24·8 995	25·7 995	78·8 26 C.	26·6 995	27·6 995	28·5 995	29·5 994	30·5 994	31·5 994	32·5 994	33·5 994	34·5 993	35·5 993
80·6 27 C.	17·4 996	18·3 996	19·2 996	20·1 996	20·9 996	21·8 996	22·7 996	23·6 996	24·4 995	25·3 995	80·6 27 C.	26·2 995	27·2 994	28·1 994	29·1 994	30·1 994	31·1 993	32·1 993	33·1 993	34·1 993	35·1 993
82·4 28 C.	17 996	18 996	18·9 996	19·7 995	20·6 995	21·5 995	22·3 995	23·2 995	24 995	24·9 994	82·4 28 C	25·8 994	26·8 994	27·7 994	28·7 993	29·7 993	30·7 993	31·7 993	32·7 993	33·7 992	34·7 992
84·2 29 C.	16·7 996	17·6 996	18·5 995	19·4 995	20·3 995	21·1 995	21·9 995	22·8 994	23·7 994	24·5 994	84·2 29 C.	25·4 994	26·4 993	27·3 993	28·3 993	29·3 993	30·3 992	31·3 992	32·3 992	33·3 992	34·3 992
86·0 30 C.	16·4 995	17·3 995	18·2 995	19·1 995	19·9 995	20·8 994	21·6 994	22·5 994	23·3 994	24·2 994	86·0 30 C.	25·1 993	26 993	26·9 993	27·9 993	28·9 992	29·9 992	30·9 992	31·9 991	32·9 991	33·9 991

(GAY-LUSSAC).—TABLE I.—Continued.

Temp Fahr.	Observed per centage of the Alcoholometer.									
	41 p.cent.	42 p.cent.	43 p.cent.	44 p.cent.	45 p.cent.	46 p.cent.	47 p.cent.	48 p.cent.	49 p.cent.	50 p.cent.
32·0° 0° C.	46·9 1011	47·9 1011	48·8 1011	49·8 1011	50·7 1011	51·7 1011	52·6 1012	53·5 1012	54·5 1012	55·4 1012
33·8 1 C.	46·5 1010	47·5 1010	48.4 1010	49·4 1010	50·3 1010	51·3 1011	52·2 1011	53·2 1011	54·2 1011	55·1 1011
35·6 2 C.	46·1 1009	47·1 1009	48·1 1009	49 1009	49·9 1010	50·9 1010	51·8 1010	52·8 1010	53·8 1010	54·7 1010
37·4 3 C.	45·8 1008	46·7 1009	47·7 1009	48·6 1009	49·6 1009	50·5 1009	51·5 1009	52·4 1009	53·4 1009	54·3 1009
39·2 4 C.	45·4 1008	46·4 1008	47·4 1008	48·3 1008	49·2 1008	50·2 1008	51·1 1008	52·1 1008	53 1008	54 1009
41·0 5 C.	45 1007	45·9 1007	46·9 1007	47·9 1007	48·8 1007	49·8 1007	50·7 1007	51·7 1008	52·7 1008	53·6 1008
42·8 6 C.	44·6 1006	45·5 1006	46·5 1006	47·5 1007	48·4 1007	49·4 1007	50·4 1007	51·4 1007	52·4 1007	53·3 1007
44·6 7 C.	44·2 1005	45·1 1006	46·1 1006	47·1 1006	48·1 1006	49·1 1006	50·1 1006	51 1006	52 1006	52·9 1006
46·4 8 C.	43·8 1005	44·8 1005	45·8 1005	46·8 1005	47·7 1005	48·7 1005	49·7 1005	50·6 1005	51·6 1005	52·6 1005
48·2 9 C.	43·4 1004	44·4 1004	45·4 1004	46·4 1004	47·3 1004	48·3 1004	49·3 1005	50·2 1005	51·2 1005	52·2 1005
50·0 10 C.	43 1003	44 1004	45 1004	46 1004	46·9 1004	47·9 1004	48·9 1004	49·9 1004	50·9 1004	51·8 1004
51·8 11 C.	42·6 1003	43·6 1003	44·6 1003	45·6 1003	46·6 1003	47·6 1003	48·6 1003	49·5 1003	50·5 1003	51·5 1003
53·6 12 C.	42·2 1002	43·2 1002	44·2 1002	45·2 1002	46·2 1002	47·2 1002	48·2 1002	49·2 1002	50·2 1002	51·1 1002
55·4 13 C.	41·8 1001	42·8 1001	43·8 1001	44·8 1002	45·8 1002	46·8 1002	47·8 1002	48·8 1002	49·8 1002	50·8 1002
57·2 14 C.	41·4 1001	42·4 1001	43·4 1001	44·4 1001	45·4 1001	46·4 1001	47·4 1001	48·4 1001	49·4 1001	50·4 1001
59·0 15 C.	41 1000	42 1000	43 1000	44 1000	45 1000	46 1000	47 1000	48 1000	49 1000	50 1000
60·8 16 C.	40·6 999	41·6 999	42·6 999	43·6 999	44·6 999	45 6 999	46·6 999	47·6 999	48·6 999	49·6 999
62·6 17 C.	40·2 999	41·2 999	42·2 999	43·2 998	44·2 998	45·2 998	46·2 998	47·2 998	48·3 998	49·3 998
64·4 18 C.	39·8 998	40·8 998	41·8 998	42·8 998	43·8 998	44·9 998	45·9 998	46·9 998	47·9 998	48·9 998
66·2 19 C.	39·4 997	40·4 997	41·4 997	42·5 997	43·5 997	44·5 997	45·5 997	46·5 997	47·5 997	48·5 997
68·0 20 C.	39 997	40 997	41 997	42·1 997	43·1 996	44·1 996	45·1 996	46·1 996	47·2 996	48·2 996
69·8 21 C.	38·6 996	39·6 996	40.6 996	41·7 996	42·7 996	43·7 996	44·8 996	45·8 996	46·8 995	47·8 995
71·6 22 C.	38·2 996	39·2 995	40·2 995	41·3 995	42·3 995	43·3 995	44·3 995	45·3 995	46·4 995	47·4 995
73·4 23 C.	37·8 995	38·8 995	39·8 995	40·9 994	41·9 994	42·9 994	43·9 994	44·9 994	46 994	47 994
75·2 24 C.	37·4 994	38·4 994	39·4 994	40·5 994	41·5 994	42·5 994	43·6 994	44·6 994	45·6 993	46·6 993
77·0 25 C.	37 994	38 994	39 993	40·1 993	41·1 993	42·2 993	43·2 993	44·2 993	45·2 993	46·3 993
78·8 26 C.	36·5 993	37·6 993	38·6 993	39·7 993	40·7 992	41 8 992	42·8 992	43·8 992	44·9 992	45·9 992
80·6 27 C.	36·1 992	37·2 992	38·2 992	39·3 992	40·3 992	41·4 992	42·4 992	43·4 991	44·5 991	45·5 991
82·4 28 C.	35·7 992	36·8 992	37·8 992	38·9 991	39·9 991	41 991	42 991	43 991	44·1 991	45·1 990
84·2 29 C.	35·3 991	36·3 991	37·4 991	38·5 991	39·5 991	40·6 990	41·3 990	42·6 990	43·7 990	44·7 990
86·0 30 C.	34·9 991	35·9 991	37 990	38·1 990	39·1 990	40·2 990	41·2 990	42·3 989	43·3 989	44·3 989

Temp. Fahr.	Observed per centage of the Alcoholometer.									
	51 p.cent.	52 p.cent.	53 p.cent.	54 p.cent.	55 p.cent.	56 p.cent.	57 p.cent.	58 p.cent.	59 p.cent.	60 p.cent.
32·0° 0° C.	56·4 1012	57·3 1012	58·3 1012	59·2 1012	60·2 1012	61·2 1012	62·1 1012	63.1 1013	64·1 1013	65 1013
33·8 1 C.	56 1011	57 1011	57·9 1011	58·9 1011	59·9 1011	60·9 1011	61·8 1011	62·8 1012	63·8 1012	64·7 1012
35·6 2 C.	55·7 1010	56·6 1010	57·6 1010	58·5 1010	59·5 1010	60·5 1011	61·5 1011	62 4 1011	63·4 1011	64·4 1011
37·4 3 C.	55·3 1009	56·3 1009	57·2 1009	58·2 1010	59·2 1010	60·2 1010	61·1 1010	62·1 1010	63·1 1010	64·1 1010
39·2 4 C.	55 1009	56 1009	56·9 1009	57·9 1009	58·9 1009	59·8 1009	60·8 1009	61·7 1009	62·7 1009	63·7 1009
41·0 5 C.	54·6 1008	55·6 1008	56·6 1008	57·5 1008	58·5 1008	59·5 1008	60·4 1008	61·4 1008	62·4 1008	63·4 1008
42·8 6 C.	54·3 1007	55·2 1007	56·2 1007	57·1 1007	58·1 1007	59·1 1007	60·1 1007	61 1008	62 1008	63 1008
44·6 7 C.	53·9 1006	54·9 1006	55·9 1006	56·8 1006	57·8 1006	58·8 1006	59·8 1007	60·7 1007	61·7 1007	62·7 1007
46·4 8 C.	53·6 1005	54·6 1005	55·5 1006	56·5 1006	57·5 1006	58·5 1006	59·5 1006	60·4 1006	61·4 1006	62·4 1006
48·2 9 C.	53·2 1005	54·2 1005	55·1 1005	56·1 1005	57·1 1005	58·1 1005	59·1 1005	60 1005	61 1005	62 1005
50·0 10 C.	52·8 1004	53·8 1004	54·8 1004	55·8 1004	56·8 1004	57·8 1004	58·8 1004	59·7 1004	60·7 1004	61·7 1004
51·8 11 C.	52·5 1003	53·5 1003	54·4 1003	55·4 1003	56·4 1003	57·4 1003	58·4 1003	59·4 1003	60·4 1003	61·4 1003
53·6 12 C.	52·1 1002	53·1 1002	54·1 1002	55 1002	56 1002	57 1002	58 1002	59 1002	60 1002	61 1002
55·4 13 C.	51·8 1002	52·7 1002	53·7 1002	54·7 1002	55·7 1002	56·7 1002	57·7 1002	58·7 1002	59·7 1002	60·7 1002
57·2 14 C.	51·4 1001	52·3 1001	53 3 1001	54·3 1001	55·3 1001	56·3 1001	57·3 1001	58·3 1001	59·3 1001	60·3 1001
59·0 15 C.	51 1000	52 1000	53 1000	54 1000	55 1000	56 1000	57 1000	58 1000	59 1000	60 1000
60·8 16 C.	50·6 999	51·6 999	52.6 999	53·6 999	54·6 999	55·6 999	56·6 999	57·6 999	58·6 999	59·6 999
62·6 17 C.	50·3 998	51·3 998	52·3 998	53·3 998	54·3 998	55·3 998	56·3 998	57·3 998	58·3 998	59·3 998
64·4 18 C.	49·9 998	50·9 998	51·9 998	52·9 998	53·9 998	54·9 998	55·9 998	56·9 997	57·9 997	58·9 997
66·2 19 C.	49·5 997	50·6 997	51·6 997	52·6 997	53·6 997	54·6 997	55·6 997	56·6 997	57·6 997	58·6 997
68·0 20 C.	49·2 996	50·2 996	51·2 996	52·2 996	53·2 996	54·2 996	55·2 996	56 2 996	57·2 996	58·2 996
69·8 21 C.	48·8 995	49·8 995	50·8 995	51·8 995	52·9 995	53·9 995	54·9 995	55·9 995	56·9 995	57·9 995
71·6 22 C.	48·4 995	49·4 995	50·4 995	51 4 994	52·5 994	53·5 994	54·5 994	55·5 994	56·5 994	57·5 994
73·4 23 C.	48 994	49·1 994	50 1 994	51·1 994	52·1 994	53·1 994	54·1 993	55·1 993	56·1 993	57·1 993
75·2 24 C.	47·6 993	48·7 993	49·7 993	50·7 993	51 8 993	52·8 993	53·8 993	54·8 993	55·8 993	56·8 992
77·0 25 C.	47·3 993	48·3 993	49·3 993	50·3 992	51·4 992	52·4 992	53·4 992	54·4 992	55·5 992	56·5 992
78·8 26 C.	46·9 992	47·9 992	49 992	50 991	51 991	52 991	53 991	54 991	55·1 991	56·1 991
80·6 27 C.	46·5 991	47·6 991	48·6 991	49·6 991	50·7 990	51·7 990	52·7 990	53·7 990	54·8 990	55·8 990
82·4 28 C.	46·1 990	47·2 990	48·2 990	49·2 990	50·3 990	51·3 990	52·3 990	53·3 989	54·4 989	55·4 989
84·2 29 C.	45·7 990	46·8 989	47·8 989	48·9 989	49·9 989	51 989	52 989	53 989	54 989	55 988
86·0 30 C.	45·4 989	46·4 989	47·5 989	48·5 988	49·6 988	50·6 988	51·6 988	52·6 988	53·6 988	54·7 988

(GAY-LUSSAC).—TABLE I.—Continued.

Temp Fahr.	Observed per centage of the Alcoholometer.									
	61 p.cent.	62 p.cent.	63 p.cent.	64 p.cent.	65 p.cent.	66 p.cent.	67 p.cent.	68 p.cent.	69 p.cent.	70 p.cent.
32·0°	66	67	68	68·9	69·9	70·8	71·8	72·7	73·7	74·7
0° C.	1013	1013	1013	1013	1013	1013	1013	1013	1014	1014
33·8	65·7	66·7	67·7	68·6	69·6	70·5	71·5	72·4	73·4	74·3
1 C.	1012	1012	1012	1012	1012	1012	1012	1012	1013	1013
35·6	65·3	66·3	67·3	68·3	69·3	70·2	71·2	72·1	73·1	74
2 C.	1011	1011	1011	1011	1011	1011	1011	1012	1012	1012
37·4	65	66	67	68	68·9	69·9	70·8	71·8	72·8	73·7
3 C.	1010	1010	1010	1010	1010	1011	1011	1011	1011	1011
39·2	64·7	65·7	66·6	67·6	68·6	69·5	70·5	71·5	72·5	73·4
4 C.	1009	1009	1009	1010	1010	1010	1010	1010	1010	1010
41·0	64·3	65·3	66·3	67·3	68·3	69·2	70·2	71·2	72·2	73·1
5 C.	1009	1009	1009	1009	1009	1009	1009	1009	1009	1009
42·8	64	65	66	67	68	68·9	69·9	70·9	71·9	72·8
6 C.	1008	1008	1008	1008	1008	1008	1008	1008	1008	1008
44·6	63·7	64·7	65·7	66·7	67·6	68·6	69·6	70·6	71·5	72·5
7 C.	1007	1007	1007	1007	1007	1007	1007	1007	1007	1007
46·4	63·4	64·4	65·4	66·4	67·3	68·3	69·3	70·2	71·2	72·2
8 C.	1006	1006	1006	1006	1006	1006	1006	1006	1006	1006
48·2	63	64	65	66	67	67·9	68·9	69·9	70·9	71·9
9 C.	1005	1005	1005	1005	1005	1005	1005	1005	1005	1005
50·0	62·7	63·7	64·7	65·7	66·7	67·6	68·6	69·6	70·6	71·6
10 C.	1004	1004	1004	1004	1004	1004	1004	1004	1004	1004
51·8	62·4	63·4	64·4	65·4	66·4	67·3	68·3	69·3	70·3	71·3
11 C.	1003	1003	1003	1003	1003	1003	1003	1004	1004	1004
53·6	62	63	64	65	66	67	68	69	70	71
12 C.	1002	1002	1002	1002	1002	1002	1003	1003	1003	1003
55·4	61·7	62·7	63·7	64·7	65·7	66·7	67·7	68·7	69·6	70·6
13 C.	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002
57·2	61·3	62·3	63·3	64·3	65·3	66·3	67·3	68·3	69·3	70·3
14 C.	1001	1001	1001	1001	1001	1001	1001	1001	1001	1001
59·0	61	62	63	64	65	66	67	68	69	70
15 C.	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
60·8	60·6	61·7	62·7	63·7	64·7	65·7	66·7	67·7	68·7	69·7
16 C.	999	999	999	999	999	999	999	999	999	999
62·6	60·3	61·3	62·3	63·3	64·3	65·3	66·3	67·3	68·3	69·3
17 C.	998	998	998	998	998	998	998	998	998	998
64·4	59·9	61	62	63	64	65	66	67	68	69
18 C.	997	997	997	997	997	997	997	997	997	997
66·2	59·6	60·6	61·6	62·7	63·7	64·7	65·7	66·7	67·7	68·7
19 C.	997	997	997	997	997	997	997	997	996	996
68·0	59·2	60·3	61·3	62·3	63·3	64·3	65·4	66·4	67·4	68·4
20 C.	996	996	996	996	996	996	996	996	996	996
69·8	58·9	59·9	61	62	63	64	65	66	67	68·1
21 C.	995	995	995	995	995	995	995	995	995	995
71·6	58·5	59·5	60·6	61·6	62·7	63·7	64·7	65·7	66·7	67·8
22 C.	994	994	994	994	994	994	994	994	994	994
73·4	58·1	59·2	60·2	61·3	62·3	63·3	64·3	65·4	66·4	67·4
23 C.	993	993	993	993	993	993	993	993	993	993
75·2	57·8	58·9	59·9	61	62	63	64	65	66	67·1
24 C.	992	992	992	992	992	992	992	992	992	992
77·0	57·5	58·5	59·5	60·6	61·6	62·6	63·7	64·7	65·7	66·7
25 C.	992	992	992	991	991	991	991	991	991	991
78·8	57·1	58·1	59·2	60·2	61·3	62·3	63·3	64·3	65·3	66·4
26 C.	991	991	991	991	990	990	990	990	990	990
80·6	56·8	57·8	58·9	59·9	60·9	61·9	63	64	65	66
27 C.	990	990	990	990	990	990	989	989	989	989
82·4	56·4	57·5	58·5	59·5	60·6	61·6	62·6	63·7	64·7	65·7
28 C.	989	989	989	989	989	989	989	989	989	988
84·2	56	57·1	58·1	59·2	60·2	61·2	62·3	63·3	64·3	65·4
29 C.	988	988	988	988	988	988	988	988	988	988
86·0	55·7	56·7	57·8	58·8	59·9	60·9	61·9	63	64	65
30 C.	988	987	987	987	987	987	987	987	987	987

Temp. Fahr.	Observed per centage of the Alcoholometer.									
	71 p.cent.	72 p.cent.	73 p.cent.	74 p.cent.	75 p.cent.	76 p.cent.	77 p.cent.	78 p.cent.	79 p.cent.	80 p.cent.
32·0°	75·6	76·6	77·6	78·6	79·5	80·5	81·5	82·4	83·3	84·3
0° C.	1014	1014	1014	1014	1014	1014	1014	1014	1014	1014
33·8	75·3	76·3	77·3	78·3	79·2	80·2	81·2	82·1	83·1	84
1 C.	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013
35·6	75	76	77	78	78·9	79·9	80·9	81·9	82·8	83·7
2 C.	1012	1012	1012	1012	1012	1012	1012	1012	1012	1012
37·4	74·7	75·7	76·7	77·7	78·6	79·6	80·6	81·6	82·5	83·5
3 C.	1011	1011	1011	1011	1011	1011	1011	1011	1011	1011
39·2	74·4	75·3	76·3	77·3	78·3	79·3	80·3	81·3	82·2	83·2
4 C.	1010	1010	1010	1010	1010	1010	1010	1010	1010	1010
41·0	74·1	75	76	77	78	79	80	81	81·9	82·9
5 C.	1009	1009	1009	1009	1009	1009	1009	1009	1010	1010
42·8	73·8	74·7	75·7	76·7	77·7	78·7	79·7	80·7	81·6	82·6
6 C.	1008	1008	1008	1008	1008	1008	1008	1008	1008	1009
44·6	73·5	74·4	75·4	76·4	77·4	78·4	79·4	80·4	81·4	82·3
7 C.	1007	1007	1007	1007	1007	1007	1007	1007	1007	1008
46·4	73·2	74·1	75·1	76·1	77·1	78·1	79·1	80·1	81·1	82
8 C.	1006	1006	1006	1006	1006	1006	1007	1007	1007	1007
48·2	72·9	73·8	74·8	75·8	76·8	77·8	78·8	79·8	80·8	81·7
9 C.	1005	1005	1005	1005	1005	1005	1006	1006	1006	1006
50·0	72·6	73·5	74·5	75·5	76·5	77·5	78·5	79·5	80·5	81·5
10 C	1004	1004	1005	1005	1005	1005	1005	1005	1005	1005
51·8	72·3	73·2	74·2	75·2	76·2	77·2	78·2	79·2	80·2	81·2
11 C.	1004	1004	1004	1004	1004	1004	1004	1004	1004	1004
53·6	72	72·9	73·9	74·9	75·9	76·9	77·9	78·9	79·9	80·9
12 C.	1003	1003	1003	1003	1003	1003	1003	1003	1003	1003
55·4	71·6	72·6	73·6	74·6	75·6	76·6	77·6	78·6	79·6	80·6
13 C	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002
57·2	71·3	72·3	73·3	74·3	75·3	76·3	77·3	78·3	79·3	80·3
14 C.	1001	1001	1001	1001	1001	1001	1001	1001	1001	1001
59·0	71	72	73	74	75	76	77	78	79	80
15 C	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
60·8	70·7	71·7	72.7	73·7	74·7	75·7	76·7	77·7	78·7	79·7
16 C.	999	999	999	999	999	999	999	999	999	999
62·6	70·3	71·3	72·3	73·3	74·3	75·4	76·4	77·4	78·4	79·4
17 C.	998	998	998	998	998	998	998	998	998	998
64·4	70	71	72	73	74	75·1	76·1	77·1	78·1	79·1
18 C.	997	997	997	997	997	997	997	997	997	997
66·2	69·7	70·7	71·7	72·7	73·7	74·7	75·8	76·8	77·8	78·8
19 C.	996	996	996	996	996	996	996	996	996	996
68·0	69·4	70·4	71·4	72·4	73·4	74·4	75·5	76·5	77·5	78·5
20 C.	996	996	995	995	995	995	995	995	995	995
69·8	69·1	70·1	71·1	72·1	73·1	74·1	75·2	76·2	77·2	78·2
21 C.	995	995	995	994	994	994	994	994	994	994
71·6	68·8	69·8	70·8	71·8	72·8	73·8	74·8	75·9	76·9	77·9
22 C.	994	994	994	994	993	993	993	993	993	993
73·4	68·4	69·4	70·5	71·5	72·5	73·5	74·5	75·5	76·6	77·6
23 C.	993	993	993	993	992	992	992	992	992	992
75·2	68·1	69·1	70·1	71·2	72·2	73·2	74·2	75·2	76·3	77·3
24 C	992	992	992	992	992	992	992	991	991	991
77·0	67·8	68·8	69·8	70·8	71·8	72·8	73·9	74·9	76	77
25 C.	991	991	991	991	991	991	991	991	991	991
78·8	67·4	68·4	69·5	70·5	71.5	72·5	73·6	74·6	75·6	76·7
26 C	990	990	990	990	990	990	990	990	990	990
80·6	67·1	68·1	69·2	70·2	71·2	72·2	73·3	74·3	75·3	76·3
27 C.	989	989	989	989	989	989	989	989	989	989
82·4	66·8	67·8	68·8	69·9	70·9	71·9	73	74	75	76
28 C	988	988	988	988	988	988	988	988	988	988
84·2	66·4	67·4	68·5	69·5	70·6	71·6	72·6	73·7	74·7	75·7
29 C.	988	987	987	987	987	987	987	987	987	987
86·0	66·1	67·1	68·2	69·2	70·3	71·3	72·3	73·3	74·4	75·4
30 C.	987	987	986	986	986	986	986	986	986	986

(GAY-LUSSAC).—TABLE I.—Concluded.

Temp Fahr.	Observed per centage of the Alcoholometer.										Temp. Fahr.	Observed per centage of the Alcoholometer.									
	81 p.cent.	82 p.cent.	83 p.cent.	84 p.cent.	85 p.cent.	86 p.cent.	87 p.cent.	88 p.cent.	89 p.cent.	90 p.cent.		91 p.cent.	92 p.cent.	93 p.cent.	94 p.cent.	95 p.cent.	96 p.cent.	97 p.cent.	98 p.cent.	99 p.cent.	100 p.cent.
32·0° 0° C.	85·2 1014	86·2 1014	87·1 1014	88 1014	88·9 1014	89·9 1015	90·8 1015	91·7 1015	92·6 1015	93·6 1015	32·0° 0° C.	94·5 1015	95·3 1015	96·2 1015	97·1 1015	98 1015	98·8 1015	99·7 1016			
33·8 1 C.	85 1013	85·9 1013	86·8 1013	87·8 1013	88·7 1013	89·6 1014	90·5 1014	91·5 1014	92·4 1014	93·3 1014	33·8 1 C.	94·3 1014	95·1 1014	96 1014	96·9 1014	97·8 1014	98·6 1014	99·5 1014			
35·6 2 C.	84·7 1012	85·6 1012	86·6 1012	87·5 1012	88·5 1012	89·4 1013	90·3 1013	91·2 1013	92·2 1013	93·1 1013	35·6 2 C.	94 1013	94·9 1013	95·8 1013	96·7 1013	97·6 1013	98·5 1013	99·3 1014			
37·4 3 C.	84·4 1011	85·4 1011	86·3 1011	87·3 1011	88·2 1011	89·2 1012	90·1 1012	91 1012	91·9 1012	92·9 1012	37·4 3 C.	93·8 1012	94·7 1012	95·6 1012	96·5 1012	97·4 1012	98·3 1012	99·2 1012	1012		
39·2 4 C.	84·2 1011	85·1 1011	86·1 1011	87 1011	87·9 1011	88·9 1011	89·8 1011	90·8 1011	91·7 1011	92·7 1011	39·2 4 C.	93·6 1011	94·5 1011	95·4 1011	96·3 1011	97·2 1011	98·1 1011	99 1011	99·9 1011		
41·0 5 C.	83·9 1010	84·8 1010	85·8 1010	86·7 1010	87·7 1010	88·6 1010	89·6 1010	90·5 1010	91·5 1010	92·4 1010	41·0 5 C.	93·4 1010	94·3 1010	95·2 1010	96·1 1010	97 1010	97·9 1010	93·8 1010	99·7 1010		
42·8 6 C.	83·6 1009	84·5 1009	85·5 1009	86·5 1009	87·4 1009	88·4 1009	89·3 1009	90·2 1009	91·2 1009	92·2 1009	42·8 6 C.	93·1 1009	94·1 1009	95 1009	95·9 1009	96·8 1009	97·8 1009	98·7 1009	99·6 1009		
44·6 7 C.	83·3 1008	84·2 1008	85·2 1008	86·2 1008	87·2 1008	88·1 1008	89·1 1008	90 1008	91 1008	91·9 1008	44·6 7 C.	92·9 1008	93·9 1008	94·8 1008	95·7 1008	96·6 1008	97·6 1008	98·5 1008	99·4 1008		
46·4 8 C.	83 1007	84 1007	85 1007	85·9 1007	86·9 1007	87·9 1007	88·8 1007	89·8 1007	90·7 1007	91·7 1007	46·4 8 C.	92·7 1007	93·6 1007	94·6 1007	95·5 1007	96·4 1007	97·4 1007	98·3 1007	99·2 1007	1007	
48·2 9 C.	82·7 1006	83·7 1006	84·7 1006	85·7 1006	86·6 1006	87·6 1006	88·6 1006	89·5 1006	90·5 1006	91·5 1006	48·2 9 C.	92·5 1006	93·4 1006	94·4 1006	95·3 1006	96·2 1006	97·2 1006	98·1 1006	99·1 1006	100 1006	
50·0 10 C.	82·4 1005	83·4 1005	84·4 1005	85·4 1005	86·4 1005	87·4 1005	88·3 1005	89·3 1005	90·2 1005	91·2 1005	50·0 10 C.	92·2 1005	93·2 1005	94·2 1005	95·1 1005	96 1005	97 1005	98 1005	98·9 1005	99·9 1005	
51·8 11 C.	82·2 1004	83·1 1004	84·1 1004	85·1 1004	86·1 1004	87·1 1004	88 1004	89 1004	90 1004	91 1004	51·8 11 C.	92 1004	92·9 1004	93·9 1004	94·9 1004	95·8 1004	96·8 1004	97·8 1004	98·7 1004	99·7 1004	
53·6 12 C.	81·9 1003	82·9 1003	83·9 1003	84·8 1003	85·8 1003	86·8 1003	87·8 1003	88·7 1003	89·7 1003	90·7 1003	53·6 12 C.	91·7 1003	92·7 1003	93·7 1003	94·7 1003	95·6 1003	96·6 1003	97·6 1003	98·5 1003	99·5 1003	
55·4 13 C.	81·6 1002	82·6 1002	83·6 1002	84·6 1002	85·5 1002	86·5 1002	87·5 1002	88·5 1002	89·5 1002	90·5 1002	55·4 13 C.	91·5 1002	92·5 1002	93·5 1002	94·4 1002	95·4 1002	96·4 1002	97·4 1002	98·4 1002	99·3 1002	
57·2 14 C.	81·3 1001	82·3 1001	83·3 1001	84·3 1001	85·3 1001	86·3 1001	87·3 1001	88·2 1001	89·2 1001	90·2 1001	57·2 14 C.	91·2 1001	92·2 1001	93·2 1001	94·2 1001	95·2 1001	96·2 1001	97·2 1001	98·2 1001	99·2 1001	
59·0 15 C.	81 1000	82 1000	83 1000	84 1000	85 1000	86 1000	87 1000	88 1000	89 1000	90 1000	59·0 15 C.	91 1000	92 1000	93 1000	94 1000	95 1000	96 1000	97 1000	98 1000	99 1000	100 1000
60·8 16 C.	80·7 999	81·7 999	82·7 999	83·7 999	84·7 999	85·7 999	86·7 999	87·7 999	88·7 999	89·7 999	60·8 16 C.	90·8 999	91·8 999	92.8 999	93·8 999	94·8 999	95·8 999	96·8 999	97·8 999	98·8 999	99·8 999
62·6 17 C.	80·4 998	81·4 998	82·4 998	83·4 998	84·4 998	85·4 998	86·4 998	87·4 998	88·4 998	89·5 998	62·6 17 C.	90·5 998	91·5 998	92·6 998	93·6 998	94·6 998	95·6 998	96·6 998	97·6 998	98·7 998	99·7 998
64·4 18 C.	80·1 997	81·1 997	82·1 997	83·1 997	84·1 997	85·2 997	86·2 997	87·2 997	88·2 997	89·2 997	64·4 18 C.	90·2 997	91·3 997	92·3 997	93·3 997	94·3 997	95·4 997	96·4 997	97·4 997	98·5 997	99·5 997
66·2 19 C.	79·8 996	80·8 996	81·9 996	82·9 996	83·9 996	84·9 996	85·9 996	86·9 996	87·9 996	88·9 996	66·2 19 C.	90 996	91·1 996	92·1 996	93·1 996	94·1 996	95·2 996	96·2 996	97·3 996	98·3 996	99·3 996
68·0 20 C.	79·5 995	80·5 995	81·6 995	82·6 995	83·6 995	84·6 995	85·6 995	86·6 995	87·7 995	88·7 995	68·0 20 C.	89·7 995	90·8 995	91·8 995	92·9 995	93·9 995	95 995	96 995	97·1 995	98·1 995	99·1 995
69·8 21 C.	79·2 994	80·2 994	81·3 994	82·3 994	83·3 994	84·3 994	85·3 994	86·4 994	87·4 994	88·4 994	69·8 21 C.	89·5 994	90·5 994	91·6 994	92·6 994	93·7 994	94·7 994	95·8 994	96·9 994	97·9 994	99 994
71·6 22 C.	78·9 993	79·9 993	81 993	82 993	83 993	84 993	85 993	86·1 993	87·1 993	88·2 993	71·6 22 C.	89·2 993	90·2 993	91·3 993	92·4 993	93·4 993	94·5 993	95·6 993	96·7 993	97·7 993	98·8 993
73·4 23 C.	78·6 992	79·6 992	80·7 992	81·7 992	82·7 992	83·8 992	84·8 992	85·8 992	86·8 992	87·9 992	73·4 23 C.	89 992	90 992	91·1 992	92·1 992	93·2 992	94·3 992	95·4 992	96·5 992	97·5 992	98·6 992
75·2 24 C	78·3 991	79·3 991	80·4 991	81·4 991	82·4 991	83·5 991	84·5 991	85·5 991	86·5 991	87·6 991	75·2 24 C.	88·7 991	89·7 991	90·8 991	91·9 991	93 991	94·1 991	95·2 991	96·2 991	97·3 991	98·4 991
77·0 25 C.	78 991	79 991	80·1 990	81·1 990	82·1 990	83·2 990	84·2 990	85·2 990	86·3 990	87·4 990	77·0 25 C.	88·4 990	89·5 990	90·6 990	91·6 990	92·7 990	93·8 990	94·9 990	96 990	97·1 990	98·2 990
78·8 26 C.	77·7 990	78·7 989	79·8 989	80·8 989	81·8 989	82·9 989	83·9 989	84·9 989	86 989	87·1 989	78·8 26 C.	88·2 989	89·2 989	90·3 989	91·4 989	92.5 989	93·6 989	94·7 989	95·8 989	96·9 989	98·1 989
80·6 27 C.	77·4 989	78·4 988	79·5 988	80·5 988	81·5 988	82·6 988	83·6 988	84·7 988	85·7 988	86·8 988	80·6 27 C.	87·9 988	89 988	90·1 988	91·1 988	92·2 988	93·4 988	94·5 988	95·6 987	96·7 987	97·9 987
82·4 28 C.	77·1 988	78·1 988	79·2 987	80·2 987	81·2 987	82·3 987	83·3 987	84·4 987	85·4 987	86·5 987	82·4 28 C.	87·6 987	88·7 987	89·8 987	90·9 987	92 987	93·1 987	94·3 987	95·4 986	96·5 986	97·7 986
84·2 29 C.	76·7 987	77·8 987	78·9 987	79·9 986	80·9 986	82 986	83 986	84·1 986	85·1 986	86·2 986	84·2 29 C.	87·3 986	88·4 986	89·5 986	90·6 986	91·7 986	92·9 986	94·1 986	95·2 986	96·3 985	97·5 985
86·0 30 C.	76·4 986	77·7 986	78·6 986	79·6 986	80·6 985	81·7 985	82·7 985	83·8 985	84·9 985	86 985	86·0 30 C.	87·1 985	88·2 985	89·3 985	90·4 985	91·5 985	92·7 985	93·8 985	95 985	96·1 984	97·3 984

The second of GAY-LUSSAC'S tables corresponds with Table VII. of TRALLES, and gives directly, though less accurately, that which by the former table is only obtained by a calculation, namely, the percentage by volume of the liquid at any temperature at which it is tested, from the observed per cent. Thus, if, as in the former example, the alcoholometer indicated 59 per cent. in the liquid at 77° Fahr., the observed per cent., 59, is sought for in the upper horizontal column, and in the vertical column below it that number is then taken which is in the same horizontal column with the observed temperature, 77° Fahr., in the left-hand column, which in this case is 55, or the liquid at the observed temperature of 77° Fahr. contains 55 volumes of anhydrous alcohol.

(GAY-LUSSAC).—ALCOHOLOMETRIC TABLE II.

To find directly the percentage of absolute alcohol of a liquid at any temperature from the observed percentage at the same temperature.

Temp.		Observed per centage of the Alcoholometer.																			
Fahr.	Cent.	1 p.cent.	2 p.cent.	3 p.cent.	4 p.cent.	5 p.cent.	6 p.cent.	7 p.cent.	8 p.cent.	9 p.cent.	10 p.cent.	11 p.cent.	12 p.cent.	13 p.cent.	14 p.cent.	15 p.cent.	16 p.cent.	17 p.cent.	18 p.cent.	19 p.cent.	20 p.cent.
32·0	0	1·3	2.4	3·4	4·4	5·4	6·5	7 5	8·6	9·7	10·9	12·2	13·4	14·7	16·1	17·5	19	20·4	21·7	23	24·3
33·8	1											—	13·4	14·7	16	17·3	18·7	20·1	21·4	22·7	24
35·6	2											—	13·4	14·7	16	17·2	18·6	19·9	21·2	22·4	23·7
37·4	3											—	13·3	14·6	15·9	17·1	18·3	19·7	20·9	22·1	23·4
39·2	4											—	13·3	14·5	15·8	16·9	18·1	19·4	20·7	21·9	23·1
41·0	5	1·4	2·5	3·5	4·5	5·5	6·6	7·7	8·7	9·8	10·9	12·1	13·2	14·4	15·7	16·8	18	19·2	20·5	21·6	22·8
42·8	6											—	13·1	14·3	15·6	16·7	17·8	19	20·3	21·4	22·5
44·6	7											—	13	14·2	15·4	16·6	17·7	18·8	20	21	22·1
46·4	8											—	13	14·1	15·3	16·4	17·5	18·6	19·7	20·7	21·8
48·2	9											—	12·9	14	15·1	16·2	17·3	18·4	19·5	20·5	21·6
50 0	10	1·4	2·4	3·4	4·5	5·5	6·5	7·5	8·5	9·5	10·6	11·7	12·7	13·8	14·9	16	17	18·1	19·2	20·2	21·3
51 8	11	1·3	2·4	3·4	4·4	5·4	6·4	7·4	8·4	9·4	10·5	11·6	12·6	13·6	14·7	15·8	16·8	17·9	19	20	21
53·6	12	1·2	2·3	3·3	4·3	5·3	6·3	7·3	8·3	9·3	10·4	11·5	12·5	13·5	14·6	15·6	16·6	17·6	18·7	19·7	20·7
55·4	13	1·2	2·2	3·2	4·2	5·2	6·2	7·2	8·2	9·2	10·3	11·4	12·4	13·4	14·4	15·4	16·4	17·4	18·5	19·5	20·5
57·2	14	1·1	2·1	3·1	4·1	5·1	6·1	7·1	8·1	9·1	10·2	11·2	12·2	13·2	14·2	15·2	16·2	17·2	18·2	19·2	20·2
59·0	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
60·8	16	0·9	1·9	2·9	3·9	4·9	5·9	6 9	7·9	8·9	9·9	10·9	11·9	12·9	13·9	14·9	15·9	16·9	17·8	18·7	19·7
62·6	17	0·8	1·8	2·8	3·8	4·8	5·8	6·8	7·8	8·8	9·8	10·8	11·7	12·7	13·7	14·7	15·6	16·6	17·5	18·4	19·4
64·4	18	0·7	1·7	2·7	3·7	4·7	5·7	6·7	7·7	8·7	9·7	10·7	11·6	12·5	13·5	14·5	15·4	16·3	17·3	18·2	19·1
66·2	19	0·6	1·6	2·6	3·6	4·5	5·5	6·5	7·5	8·5	9·5	10·5	11·4	12·4	13·3	14·3	15·2	16·1	17	17·9	18·8
68·0	20	0·5	1·5	2·4	3·4	4·4	5·4	6·4	7·3	8·3	9·3	10·3	11·2	12·2	13·1	14	14·9	15·8	16·7	17·6	18·5
69·8	21	0·4	1·4	2·3	3·3	4·3	5·2	6·2	7·1	8·1	9·1	10·1	11	11·9	12·8	13·7	14·6	15·5	16·4	17·3	18·2
71·6	22	0·3	1·3	2·2	3·2	4·1	5·1	6·1	7	7·9	8·9	9·9	10·8	11·7	12·6	13·5	14·4	15·3	16·2	17	17·9
73·4	23	0·1	1·1	2·1	3·1	4	4·9	5·9	6·8	7·8	8·7	9·7	10·6	11·5	12·4	13·3	14·1	15	15·9	16·7	17·6
75·2	24	0·0	1	1·9	2·9	3·8	4·8	5·8	6·7	7·6	8 5	9·5	10·4	11·3	12·2	13·1	13·9	14·8	15·7	16·5	17·4
77·0	25	—	0·8	1·7	2·7	3·6	4·6	5·5	6·5	7·4	8·3	9·3	10·2	11·1	12	12·8	13·6	14·5	15·4	16·2	17·1
78·8	26	—	0·7	1·6	2·6	3·5	4·4	5·4	6·3	7 2	8·1	9	9·9	10·8	11·7	12·6	13·4	14·2	15·1	15·9	16·7
80·6	27	—	0·5	1·5	2·4	3·3	4·3	5·2	6·1	7	7·9	8·8	9·7	10·6	11·5	12·3	13·1	13·9	14·8	15·6	16·4
82·4	28	—	0·3	1·3	2·2	3·1	4·1	5	5·9	6·8	7·7	8·6	9·5	10·3	11 2	12	12·8	13·6	14·4	15·2	16
84·2	29	—	0·1	1·1	2	2·9	3·9	4·8	5·7	6·6	7·5	8·4	9·2	10·1	11	11 7	12·5	13·3	14·1	14·9	15 7
86·0	30	—	0·0	0·9	1·9	2·8	3·7	4·6	5·5	6·4	7·3	8·1	9	9·8	10·7	11 5	12·3	13	13·8	14·6	15·4

Temp																					
Fahr.	Cent.	21 p.cent.	22 p.cent.	23 p.cent.	24 p.cent.	25 p.cent.	26 p.cent.	27 p.cent.	28 p.cent.	29 p.cent.	30 p.cent.	31 p.cent.	32 p.cent.	33 p.cent.	34 p.cent.	35 p.cent.	36 p cent.	37 p.cent.	38 p.cent.	39 p.cent.	40 p.cent.
32·0	0	25·7	27·1	28·5	29·9	31·1	32·3	33·4	34·5	35·6	36·6	37·6	38·5	39·6	40·6	41·5	42·5	43·5	44·4	45·4	46·4
33·8	1	25·4	26·8	28·1	29·4	30·6	31·8	32·9	34	35·1	36·1	37·1	38·1	39·1	40·1	41·2	42·2	43·1	44·1	45	46
35·6	2	25	26·4	27·6	28·9	30·2	31·4	32·5	33·5	34·6	35·6	36·7	37·7	38·7	39·7	40·7	41·7	42·7	43·7	44·6	45·5
37·4	3	24·7	26	27·3	28·6	29·8	31	32·1	33·1	34·1	35·2	36·2	37·3	38·3	39·3	40·3	41·3	42·3	43·2	44·2	45·2
39·2	4	24·4	25·7	26·9	28·1	29·3	30·6	31·6	32·7	33·7	34·7	35·7	36·7	37·7	38·8	39·8	40·8	41·8	42·8	43·8	44·8
41·0	5	24·1	25·3	26·5	27·7	28·9	30·1	31·2	32·3	33·3	34·3	35·3	36·3	37·3	38·3	39·3	40·3	41·4	42·4	43·4	44·4
42·8	6	23·7	25	26·1	27·3	28·5	29·7	30·8	31·8	32·8	33·8	34·9	35·9	36·9	37·9	38·9	39·9	40·9	41·9	42·9	43·9
44·6	7	23·4	24·7	25·8	27	28·1	29·3	30·3	31·3	32·3	33·3	34·3	35·4	36·4	37·4	38 4	39·4	40·4	41·4	42·4	43·4
46·4	8	23	24·2	25·4	26·6	27·7	28·9	29·9	30·9	31·9	32·9	33·9	34·9	35·9	36·9	38	39	40	41	42	43
48·2	9	22·7	23·9	25	26·2	27·3	28·5	29·5	30·5	31·5	32·5	33·5	34·5	35·5	36·5	37·5	38·6	39 6	40·6	41·6	42·6
50·0	10	22·4	23·5	24·6	25·8	26·9	28	29·1	30·1	31·1	32·1	33·1	34·1	35·1	36·1	37·1	38·1	39·1	40·1	41·1	42·1
51·8	11	22·1	23·2	24·3	25·4	26·5	27·7	28·7	29·7	30·7	31·7	32·7	33·7	34·7	35·7	36·7	37·7	38·7	39·7	40·7	41·7
53·6	12	21·8	22·9	24	25·1	26·1	27·2	28·2	29·2	30·2	31·2	32·2	33·2	34·3	35·3	36·3	37·3	38·3	39·3	40·3	41·3
55·4	13	21 5	22·6	23·7	24·7	25·7	26·8	27·8	28·8	29·8	30·8	31·8	32·8	33·8	34·8	35·8	36·8	37·8	38·8	39·8	40·9
57·2	14	21·2	22·3	23·3	24·3	25·3	26·4	27·4	28·4	29·4	30·4	31·4	32·4	33·4	34·4	35·4	36·4	37·4	38·4	39·4	40·4
59·0	15	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
60·8	16	20·7	21·7	22·7	23·7	24·7	25·7	26·6	27·6	28·6	29·6	30·6	31·6	32·5	33·5	34·5	35·5	36·5	37·5	38·5	39·5
62·6	17	20·4	21·4	22·4	23·4	24·4	25·4	26·3	27·3	28·2	29·2	30·2	31·2	32·1	33·1	34·1	35·1	36·1	37·1	38·1	39·1
64·4	18	20·1	21·1	22	23	24	25	25·9	26·9	27·8	28·8	29·8	30·8	31·7	32·6	33.6	34·6	35·6	36·6	37·6	38·6
66·2	19	19·8	20·8	21·7	22·7	23·6	24·6	25·5	26·4	27·3	28·3	29·3	30·3	31·2	32·2	33·2	34·2	35·2	36·2	37·2	38·2
68·0	20	19·5	20·5	21·4	22·4	23·3	24·3	25·2	26·1	27	27·9	28·9	29·9	30·8	31·8	32·8	33·8	34·8	35·8	36·8	37·8
69·8	21	19·1	20·1	21·1	22·1	22·9	23·9	24·8	25·6	26·6	27·5	28·5	29·5	30·4	31·4	32·4	33·4	34·4	35·4	36·4	37·4
71·6	22	18·8	19·8	20·7	21·6	22·5	23·5	24·3	25·2	26·2	27·1	28·1	29·1	30	31	32	33	34	35	36	36·9
73·4	23	18·5	19·4	20·3	21·3	22·2	23·1	24	24·9	25·8	26·7	27·7	28·7	29·6	30·6	31·6	32·6	33·5	34·5	35·5	36·5
75·2	24	18·2	19·1	20	21	21·8	22·7	23·6	24·5	25·4	26·3	27·3	28·3	29·2	30·2	31·1	32·1	33·1	34·1	35·1	36·1

(GAY-LUSSAC).—TABLE II.—Continued.

Temp.		Observed per centage of the Alcoholometer.																			
Fahr.	Cent.	21 p.cent.	22 p.cent.	23 p.cent.	24 p.cent.	25 p.cent.	26 p.cent.	27 p.cent.	28 p.cent.	29 p.cent.	30 p.cent.	31 p.cent.	32 p.cent.	33 p.cent.	34 p.cent.	35 p.cent.	36 p.cent.	37 p.cent.	38 p.cent.	39 p.cent.	40 p.cent.
77·0	25	17·9	18·8	19·7	20·6	21·5	22·4	23·2	24·2	25·1	26	26·9	27·9	28·8	29·7	30·7	31·7	32·7	33·7	34·7	35·7
78·8	26	17·6	18·5	19·4	20·3	21·2	22·1	22·9	23·8	24·7	25·6	26·5	27·5	28·4	29·3	30·3	31·3	32·3	33·3	34·3	35·3
80·6	27	17·3	18·2	19·1	20	20·8	21·7	22·6	23·5	24·3	25·2	26·1	27·1	27·9	28·9	29·9	30·9	31·9	32·9	33·9	34·8
82·4	28	16·9	17·9	18·8	19·6	20·5	21·4	22·2	23·1	23·9	24·8	25·7	26·6	27·5	28·5	29·5	30·5	31·5	32·5	33·5	34·4
84·2	29	16·6	17·5	18·4	19·3	20·2	21	21·8	22·7	23·6	24·4	25·2	26·2	27·1	28·1	29·1	30·1	31·1	32·1	33·1	34
86·0	30	16·3	17·2	18·1	19	19·8	20·7	21·5	22·4	23·2	24	24·9	25·8	26·7	27·7	28·7	29·7	30·7	31·6	32·6	33·6

Temp. Fahr.	Temp. Cent.	41 p.cent.	42 p.cent.	43 p.cent.	44 p.cent.	45 p.cent.	46 p.cent.	47 p.cent.	48 p.cent.	49 p.cent.	50 p.cent.	51 p.cent.	52 p.cent.	53 p.cent.	54 p.cent.	55 p.cent.	56 p.cent.	57 p.cent.	58 p.cent.	59 p.cent.	60 p.cent.
32·0	0	47·4	48·4	49·3	50·3	51·3	52·3	53·2	54·1	55·1	56·1	57·1	58	59	59·9	60·9	61·9	62·9	63·9	64·9	65·8
33·8	1	47	48	48·9	49·9	50·8	51·8	52·8	53·7	54·7	55·7	56·7	57·6	58·6	59·6	60·6	61·6	62·5	63·5	64·5	65·5
35·6	2	46·5	47·5	48·5	49·5	50·4	51·4	52·3	53·3	54·3	55·3	56·3	57·2	58·2	59·2	60·2	61·2	62·1	63·1	64·1	65·1
37·4	3	46·2	47·1	48·1	49	50	51	52	52·9	53·9	54·8	55·8	56·8	57·8	58·8	59·8	60·8	61·7	62·7	63·7	64·7
39·2	4	45·8	46·7	47·7	48·7	49·6	50·6	51·5	52·5	53·5	54·5	55·5	56·5	57·4	58·4	59·4	60·3	61·3	62·3	63·3	64·3
41·0	5	45·3	46·2	47·2	48·2	49·2	50·2	51·1	52·1	53·1	54	55	56	57	58	59	60	60·9	61·9	62·9	63·9
42·8	6	44·9	45·8	46·8	47·8	48·8	49·8	50·8	51·7	52·7	53·7	54·7	55·6	56·6	57·5	58·5	59·5	60·5	61·5	62·5	63·5
44·6	7	44·4	45·4	46·4	47·4	48·4	49·4	50·4	51·3	52·3	53·2	54·2	55·2	56·2	57·1	58·1	59·1	60·1	61·1	62·1	63·1
46·4	8	44	45	46	47	47·9	48·9	49·9	50·9	51·9	52·9	53·9	54·9	55·8	56·8	57·8	58·8	59·8	60·8	61·8	62·8
48·2	9	43·6	44·6	45·6	46·6	47·5	48·5	49·5	50·5	51·5	52·5	53·5	54·5	55·4	56·4	57·4	58·4	59·4	60·4	61·4	62·4
50·0	10	43·1	44·1	45·1	46·1	47·1	48·1	49·1	50·1	51·1	52	53	54	55	56	57	58	59	60	61	62
51·8	11	42·7	43·7	44·7	45·7	46·7	47·7	48·7	49·7	50·7	51·7	52·7	53·7	54·6	55·6	56·6	57·6	58·6	59·6	60·6	61·6
53·6	12	42·3	43·3	44·3	45·3	46·3	47·3	48·3	49·3	50·3	51·2	52·2	53·2	54·2	55·2	56·2	57·2	58·2	59·2	60·2	61·2
55·4	13	41·9	42·9	43·9	44·9	45·9	46·9	47·9	48·9	49·9	50·9	51·9	52·8	53·8	54·8	55·8	56·8	57·8	58·8	59·8	60·8
57·2	14	41·4	42·4	43·4	44·4	45·4	46·4	47·4	48·4	49·4	50·4	51·4	52·4	53·4	54·4	55·4	56·4	57·4	58·4	59·4	60·4
59·0	15	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
60·8	16	40·6	41·6	42·6	43·6	44·6	45·6	46·6	47·6	48·6	49·6	50·6	51·6	52·6	53·6	54·6	55·6	56·6	57·6	58·6	59·6
62·6	17	40·1	41·1	42·1	43·1	44·1	45·2	46·2	47·2	48·2	49·2	50·2	51·2	52·2	53·2	54·2	55·2	56·2	57·2	58·2	59·2
64·4	18	39·7	40·7	41·7	42·7	43·7	44·8	45·8	46·8	47·8	48·8	49·8	50·8	51·8	52·8	53·8	54·8	55·8	56·8	57·8	58·8
66·2	19	39·3	40·3	41·3	42·4	43·4	44·4	45·4	46·4	47·4	48·4	49·4	50·4	51·4	52·4	53·4	54·4	55·4	56·4	57·4	58·4
68·0	20	38·9	39·9	40·9	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
69·8	21	38·4	39·4	40·4	41·5	42·5	43·5	44·6	45·6	46·6	47·6	48·6	49·6	50·6	51·6	52·6	53·6	54·6	55·6	56·6	57·6
71·6	22	38	39	40	41·1	42·1	43·1	44·1	45·1	46·1	47·1	48·1	49·1	50·1	51·1	52·2	53·2	54·2	55·2	56·2	57·2
73·4	23	37·6	38·6	39·6	40·6	41·6	42·6	43·6	44·6	45·7	46·7	47·7	48·8	49·8	50·8	51·8	52·8	53·8	54·8	55·8	56·8
75·2	24	37·2	38·2	39·2	40·2	41·2	42·2	43·3	44·3	45·3	46·3	47·3	48·4	49·4	50·4	51·4	52·4	53·4	54·4	55·4	56·4
77·0	25	36·7	37·7	38·7	39·8	40·8	41·9	42·9	43·9	44·9	46	47	48	49	50	51	52	53	54	55	56
78·8	26	36·3	37·3	38·3	39·4	40·4	41·5	42·5	43·5	44·5	45·5	46·5	47·5	48·5	49·5	50·5	51·5	52·5	53·5	54·5	55·6
80·6	27	35·9	36·9	37·9	39	40	41·1	42·1	43·1	44·1	45·1	46·1	47·1	48·1	49·1	50·2	51·2	52·2	53·2	54·2	55·2
82·4	28	35·4	36·5	37·5	38·6	39·6	40·6	41·6	42·6	43·7	44·7	45·7	46·7	47·7	48·7	49·8	50·8	51·8	52·8	53·8	54·8
84·2	29	35	36	37·1	38·1	39·1	40·2	41·2	42·2	43·3	44·3	45·3	46·3	47·3	48·4	49·4	50·4	51·4	52·4	53·4	54·4
86·0	30	34·6	35·6	36·6	37·7	38·7	39·8	40·8	41·8	42·8	43.8	44·9	45·9	47	48	49	50	51	52	53	54

Temp. Fahr.	Temp. Cent.	61 p.cent.	62 p.cent.	63 p.cent.	64 p.cent.	65 p.cent.	66 p.cent.	67 p.cent.	68 p.cent.	69 p.cent.	70 p.cent.	71 p.cent.	72 p.cent.	73 p.cent.	74 p.cent.	75 p.cent.	76 p.cent.	77 p.cent.	78 p.cent.	79 p.cent.	80 p.cent.
32·0	0	66·8	67·8	68·8	69·8	70·8	71·7	72·7	73·7	74·7	75·7	76·6	77·6	78·6	79·6	80·6	81·6	82·6	83·6	84·5	85·5
33·8	1	66·5	67·5	68·5	69·4	70·4	71·3	72·3	73·3	74·3	75·3	76·2	77·2	78·2	79·2	80·2	81·2	82·2	83·2	84·2	85·1
35·6	2	66·1	67·1	68·1	69·1	70·1	71	71·9	72·9	73·9	74·9	75·9	76·9	77·9	78·9	79·9	80·9	81·9	82·9	83·8	84·7
37·4	3	65·6	66·6	67·6	68·6	69·6	70·6	71·6	72·6	73·6	74·5	75·5	76·5	77·5	78·5	79·5	80·5	81·5	82·5	83·4	84·4
39·2	4	65·3	66·3	67·3	68·3	69·3	70·2	71·2	72·2	73·2	74·1	75·1	76·1	77·1	78·1	79·1	80·1	81·1	82·1	83	84
41·0	5	64·9	65·9	66·9	67·9	68·9	69·8	70·8	71·8	72·8	73·8	74·8	75·7	76·7	77·7	78·7	79·7	80·7	81·7	82·7	83·7
42·8	6	64·5	65·5	66·5	67·5	68·5	69·5	70·5	71·5	72·5	73·4	74·4	75·3	76·3	77·3	78·3	79·3	80·3	81·3	82·3	83·3
44·6	7	64·1	65·1	66·1	67·1	68·1	69·1	70·1	71·1	72	73	74	75	76	77	78	79	80	81	82	82·9
46·4	8	63·8	64·8	65·8	66·8	67·7	68·7	69·7	70·6	71·6	72·6	73·6	74·6	75·6	76·6	77·6	78·6	79·6	80·6	81·6	82·6
48·2	9	63·4	64·4	65·4	66·4	67·3	68·3	69·3	70·3	71·3	72·3	73·3	74·2	75·2	76·2	77·2	78·2	79·2	80·2	81·2	82·2
50·0	10	63	64	65	66	67	67·9	68·9	69·9	70·9	71·9	72·9	73·9	74·9	75·9	76·9	77·9	78·9	79·9	80·9	81·9
51·8	11	62·6	63·6	64·6	65·6	66·6	67·6	68·6	69·6	70·6	71·6	72·6	73·5	74·5	75·5	76·5	77·5	78·5	79·5	80·5	81·5
53·6	12	62·2	63·2	64·2	65·2	66·2	67·2	68·2	69·2	70·2	71·2	72·2	73·1	74·1	75·1	76·1	77·1	78·1	79·1	80·1	81·1
55·4	13	61·8	62·8	63·8	64·8	65·8	66·8	67·8	68·8	69·8	70·8	71·8	72·8	73·8	74·8	75·8	76·8	77·8	78·8	79·8	80·8
57·2	14	61·4	62·4	63·4	64·4	65·4	66·4	67·4	68·4	69·4	70·4	71·4	72·4	73·4	74·4	75·4	76·4	77·4	78·4	79·4	80·4
59·0	15	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
60·8	16	60·6	61·6	62·6	63·6	64·6	65·6	66·6	67·6	68·6	69·6	70·6	71·6	72·6	73·6	74·6	75·6	76·6	77·6	78·6	79·6
62·6	17	60·2	61·2	62·2	63·2	64·2	65·2	66·3	67·2	68·2	69·2	70·2	71·2	72·2	73·2	74·2	75·2	76·2	77·2	78·2	79·2
64·4	18	59·8	60·8	61·8	62·8	63·8	64·8	65·8	66·8	67·8	68·8	69·8	70·8	71·8	72·8	73·8	74·9	75·9	76·9	77·9	78·9
66·2	19	59·4	60·4	61·4	62·5	63·5	64·5	65·5	66·5	67·5	68·5	69·5	70·5	71·5	72·5	73·5	74·5	75·5	76·5	77·5	78·5
68·0	20	59	60	61	62	63	64	65·1	66·1	67·1	68·1	69·1	70·1	71·1	72·1	73·1	74·1	75·1	76·1	77·1	78·1
69·8	21	58·6	59·6	60·7	61·7	62·7	63·7	64·7	65·7	66·7	67·7	68·7	69·7	70·7	71·7	72·7	73·7	74·7	75·8	76·8	77·8
71·6	22	58·2	59·2	60·3	61·3	62·3	63·3	64·3	65·3	66·3	67·3	68·3	69·3	70·3	71·3	72·3	73·3	74·3	75·4	76·4	77·4
73·4	23	57·8	58·8	59·8	60·9	61·9	62·9	63·9	64·9	65·9	66·9	67·9	68·9	70	71	72	73	74	75	76	77
75·2	24	57·4	58·4	59·4	60·5	61·5	62·5	63·5	64·5	65·5	66·5	67·5	68·5	69·6	70·6	71·6	72·6	73·6	74·6	75·6	76·6
77·0	25	57	58	59	60·1	61·1	62·1	63·1	64·1	65·1	66·1	67·1	68·1	69·2	70·2	71·2	72·2	73·2	74·2	75·3	76·3
78·8	26	56·6	57·6	58·6	59·6	60·7	61·7	62·7	63·7	64·7	65·7	66·7	67·7	68·8	69·8	70·8	71·8	72·8	73·8	74·8	75·9
80·6	27	56·2	57·2	58·3	59·3	60·3	61·3	62·3	63·3	64·3	65·3	66·3	67·3	68·4	69·4	70·4	71·4	72·4	73·4	74·4	75·5
82·4	28	55·8	56·8	57·8	58·8	59·9	60·9	61·9	62·9	63·9	64·9	66	67	68	69·1	70·1	71·1	72·1	73·1	74·1	75·1
84·2	29	55·4	56·4	57·4	58·5	59·5	60·5	61·5	62·5	63·5	64·5	65·6	66·6	67·7	68·7	69·7	70·7	71·7	72·7	73·7	74·7
86·0	30	55	56	57·1	58·1	59·1	60·1	61·1	62·1	63·1	64·1	65·2	66·2	67·3	68·3	69·3	70·3	71·3	72·3	73·3	74·3

(GAY-LUSSAC).—TABLE II.—Concluded.

Temp.		Observed per centage of the Alcoholometer.																			
Fahr.	Cent.	81 p.cent.	82 p.cent.	83 p.cent.	84 p.cent.	85 p.cent.	86 p.cent.	87 p.cent.	88 p.cent.	89 p.cent.	90 p.cent.	91 p.cent.	92 p.cent.	93 p.cent.	94 p.cent.	95 p.cent.	96 p.cent.	97 p.cent.	98 p.cent.	99 p.cent.	100 p.cent.
32·0	0	86·4	87·4	88·3	89·2	90·2	91·2	92·2	93·1	94	95	95·9	96·8	97·7	98·6	99·5	100·3	101·2			
33·8	1	86·1	87	88	89	89·9	90·8	91·8	92·8	93·7	94·6	95·6	96·5	97·4	98·3	99·2	100	100·9			
35·6	2	85·7	86·6	87·6	88·6	89·6	90·5	91·5	92·4	93·4	94·3	95·2	96·1	97	97·9	98·9	99·8	100·7			
37·4	3	85·3	86·3	87·3	88·3	89·2	90·2	91·2	92·1	93	94	94·9	95·8	96·7	97·7	98·6	99·5	100·4			
39·2	4	85	86	87	88	88·9	89·9	90·8	91·8	92·7	93·7	94·6	95·5	96·4	97·4	98·3	99·2	100·1	101		
41·0	5	84·7	85·6	86·6	87·6	88·5	89·5	90·5	91·4	92·4	93·3	94·3	95·2	96·2	97·1	98	98·9	99·8	100·7		
42·8	6	84·3	85·3	86·3	87·3	88·2	89·2	90·1	91	92	93	93·9	94·9	95·9	96·8	97·7	98·7	99·6	100·5		
44·6	7	83·9	84·9	85·9	86·9	87·9	88·8	89·8	90·7	91·7	92·6	93·6	94·6	95·6	96·5	97·4	98·4	99·3	100·2		
46·4	8	83·6	84·6	85·6	86·5	87·5	88·5	89·4	90·4	91·3	92·3	93·3	94·3	95·3	96·2	97·1	98·1	99	99·9		
48·2	9	83·2	84·2	85·2	86·2	87·1	88·1	89·1	90	91	92	93	94	95	95·9	96·8	97·8	98·7	99·7	100	
50·0	10	82·8	83·8	84·8	85·8	86·8	87·8	88·7	89·7	90·7	91·7	92·7	93·7	94·7	95·6	96·5	97·5	98·5	99·4	100·4	
51·8	11	82·5	83·4	84·4	85·4	86·4	87·4	88·4	89·4	90·4	91·4	92·4	93·3	94·3	95·3	96·2	97·2	98·2	99·1	100·1	
53·6	12	82·1	83·1	84·1	85	86	87	88	89	90	91	92	93	94	95	95·9	96·9	97·9	98·8	99·8	
55·4	13	81·8	82·8	83·8	84·8	85·7	86·7	87·7	88·7	89·7	90·7	91·7	92·7	93·7	94·6	95·6	96·6	97·6	98·6	99·5	
57·2	14	81·4	82·4	83·4	84·4	85·4	86·4	87·4	88·3	89·3	90·3	91·3	92·3	93·3	94·3	95·3	96·3	97·3	98·3	99·3	
59·0	15	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
60·8	16	80·6	81·6	82·6	83·6	84·6	85·6	86·6	87·6	88·6	89·6	90·7	91·7	92·7	93·7	94·7	95·7	96·7	97·7	98·7	99·7
62·6	17	80·2	81·2	82·2	83·2	84·2	85·2	86·2	87·2	88·2	89·3	90·3	91·3	92·4	93·4	94·4	95·4	96·4	97·4	98·5	99·5
64·4	18	79·9	80·9	81·9	82·9	83·9	84·9	85·9	86·9	87·9	88·9	89·9	91	92	93	94	95·1	96·1	97·1	98·2	99·2
66·2	19	79·5	80·5	81·6	82·6	83·6	84·6	85·6	86·6	87·6	88·6	89·6	90·7	91·7	92·7	93·7	94·8	95·8	96·9	97·9	98·9
68·0	20	79·1	80·1	81·2	82·2	83·2	84·2	85·2	86·2	87·2	88·2	89·2	90·3	91·3	92·4	93·4	94·5	95·5	96·6	97·6	98·6
69·8	21	78·7	79·7	80·8	81·8	82·8	83·8	84·8	85·9	86·9	87·9	88·9	90	91	92	93·1	94·1	95·2	96·3	97·3	98·4
71·6	22	78·4	79·4	80·4	81·4	82·4	83·4	84·4	85·5	86·5	87·6	88·6	89·6	90·7	91·8	92·8	93·9	94·9	96	97	98·1
73·4	23	78	79	80·1	81·1	82·1	83·1	84·1	85·1	86·1	87·2	88·3	89·3	90·4	91·4	92·4	93·5	94·6	95·7	96·7	97·8
75·2	24	77·6	78·6	79·7	80·7	81·7	82·7	83·7	84·7	85·7	86·8	87·9	88·9	90	91·1	92·1	93·2	94·3	95·3	96·4	97·5
77·0	25	77·3	78·3	79·3	80·3	81·3	82·3	83·4	84·4	85·4	86·5	87·5	88·6	89·7	90·7	91·8	92·9	93·9	95	96·1	97·2
78·8	26	76·9	77·9	78·9	79·9	80·9	81·9	82·9	84	85	86·1	87·2	88·2	89·3	90·4	91·5	92·5	93·6	94·7	95·8	97
80·6	27	76·5	77·5	78·5	79·5	80·5	81·6	82·6	83·6	84·7	85·7	86·8	87·9	89	90	91·1	92·2	93·3	94·4	95·5	96·7
82·4	28	76·1	77·1	78·2	79·2	80·2	81·3	82·3	83·3	84·3	85·4	86·5	87·5	88·6	89·7	90·8	91·9	93	94·1	95·2	96·4
84·2	29	75·7	76·8	77·8	78·8	79·8	80·9	81·6	83	84	85	86·1	87·2	88·2	89·3	90·4	91·6	92·7	93·8	94·9	96·1
86·0	30	75·3	76·4	77·4	78·4	79·4	80·5	81·5	82·6	83·6	84·7	85·8	86·9	87·9	89	90·1	91·2	92·4	93·5	94·6	95·8

TRALLES' and GAY-LUSSAC'S alcoholometers have been very generally adopted in different countries. They both give the per cent. of alcohol by volume. If it be desired to know the per cent. by weight, it may be ascertained from the per cent. in volume of the liquid at 60°, by the following table:—

TABLE OF COMPARISON

Between the per cent. of alcohol by volume at 60° Fahr.—TRALLES'—and per cent. by weight.

Per cent.		Per cent.	
By volume.	By weight.	By weight.	By volume.
0	0·	0	0·
5	4·00	5	6·25
10	8·05	10	12·42
15	12·15	15	18·52
20	16·28	20	24·57
25	20·46	25	30·55
30	24·69	30	36·45
35	28·99	35	42·25
40	33·39	40	47·92
45	37·90	45	53·43
50	42·52	50	58·79
55	47·29	55	63·97
60	52·20	60	68·97
65	57·25	65	73·79
70	62·51	70	78·40
75	67·93	75	82·80
80	73·59	80	86·97
85	79·50	85	90·88
90	85·75	90	94·46
95	92·46	95	97·61
100	100·00	100	100·00

Knowing the percentage volume of alcohol in a liquid at any temperature, the same results are arrived at when such percentage is multiplied by the specific gravity of the pure anhydrous spirit at the normal thermometric degree—0·7939 in TRALLES' tables, and 0·7947 in GAY-LUSSAC'S—and dividing this product by the density of the liquid at the observed temperature.

TABLE BY LOWITZ,

Giving the per cent. of absolute alcohol by weight, from the specific gravity at 68° Fahr. (20° C.)

Per cent. of alcohol by weight.	Specific gravity at 68°.	Per cent. of alcohol by weight.	Specific gravity at 68°.	Per cent. of alcohol by weight.	Specific gravity at 68°.	Per cent. of alcohol by weight.	Specific gravity at 68°.
100	791	74	859	48	919	23	968
99	794	73	861	47	921	22	970
98	797	72	863	46	923	21	971
97	800	71	866	45	925	20	973
96	803	70	868	44	927	19	974
95	805	69	870	43	930	18	976
94	808	68	872	42	932	17	977
93	811	67	875	41	934	16	978
92	813	66	877	40	936	15	980
91	816	65	880	39	938	14	981
90	818	64	882	38	940	13	983
89	821	63	885	37	942	12	985
88	823	62	887	36	944	11	986
87	826	61	889	35	946	10	987
86	828	60	892	34	948	9	988
85	831	59	894	33	950	8	989
84	834	58	896	32	952	7	991
83	836	57	899	31	954	6	992
82	839	56	901	30	956	5	994
81	842	55	903	29	957	4	995
80	844	54	905	28	959	3	997
79	847	53	907	27	961	2	998
78	849	52	909	26	963	1	999
77	851	51	912	25	965	0	1000
76	853	50	914	24	966		
75	856	49	917				

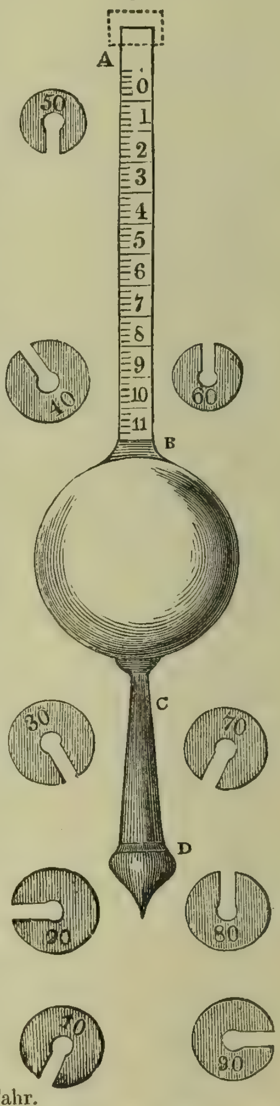
When a scale of per cent. by weight is added to TRALLES' alcoholometer, it sometimes bears the name of RICHTER'S scale.

In England, the amount of revenue which flows into the treasury annually from the trade in spirituous liquors, renders it a matter of importance to ascertain the real strength or percentage of alcohol with expedition and accuracy. Various forms of alcoholometers have therefore been constructed, some of which (Sikes' hydrometer for instance) have been sanctioned by the excise board. These instruments do not note the specific gravity of the liquid, but the excess or deficiency of alcohol above or below a standard liquor called *proof spirit*—a term which originated in a rude method of ascertaining the strength of spirit, by pouring it upon some gunpowder in a dish, and igniting it. This was called the proof. If the gunpowder took fire at the end of the combustion, the liquor was said to be above or over proof; but if the powder did not take fire the liquor was reputed to be below or under proof. The gunpowder test, however, is quite uncertain as to the quantity of spirit present in the liquid; for though the powder may be ignited when only a small quantity of spirit is used, yet on employing a larger amount, so much water may be left behind as to prevent the ignition. By parliamentary enactments the strength of proof spirit has been fixed at such a density that 13 volumes at 51° Fahr. should equal in weight 12 volumes of water at the same temperature. According to this standard, proof spirit has a gravity of ·9186 at 60° Fahr., and contains 57·27 per cent. by volume, or 49·50 per cent. by weight, of absolute alcohol. The liquors are estimated at the quantity of spirit above or below this standard, as the case may be; and when a numeral is prefixed, it means the number of volumes that are to be added to or subtracted from 100 volumes of the liquid, to bring it to standard or proof strength; thus, 20 over proof means that 100 volumes of liquor require the addition of 20 of water to bring them to proof strength, and when a liquid is 20 under proof, it is understood that 20 parts of water are to be abstracted.

Sikes' hydrometer, a description of which follows, is constructed on this principle. This is selected for special illustration on account of its being the one almost exclusively employed by the revenue in this country.

It consists of a flat stem, A B—Fig. 50—3·4 inches long, which is divided on both sides into 10 or sometimes 11 equal parts, and each of these subdivided into 5, the scale being numbered from zero—0—to 11. The stem, A B, is soldered to a brass ball, 1·6 inch in diameter, into which is fixed a small conical stem, C D, 1·13 inch long; at the end of this is a pear-shaped loaded bulb, D, half an inch in diameter. The whole instrument is made of brass, and is 6·7 inches long. Nine circular weights accompany it, numbered 10, 20, 30, 40, &c., up to 90, and there is another weight in the form of a parallelopiped. Each of the circular weights is cut into the centre, so that they can be placed on the conical stem at C, and slid down to D; in consequence of the enlargement of the cone, they cannot slip off at D, but must be brought up to C for that purpose. The weight in the form of a parallelopiped has a square notch in one of its sides, by which it can be placed on the summit, A, of the stem. In using this instrument, it is immersed in the spirit, and pressed with the finger till sunk to zero, or 0, so as to wet the whole of the stem; from the resistance felt, experience teaches which weight will be required to append to it. After slipping on the weight at C, the instrument is again immersed into the liquid, and pressed with the hand till it has descended to 0 on the scale; the pressure of the hand is then withdrawn, and the apparatus is allowed to emerge and settle at the proper point of the density of the liquid, as indicated by the scale and weights. The figure on the scale to which the hydrometer sinks is now carefully observed, and the weight placed upon the conical stem added thereto; this sum will, by reference to the tables which accompany the instrument, where the same number is found under the column *indication*, and to the temperature which corresponds with that of the liquid under examination, give the percentage of alcohol. The strength is expressed in numbers, denoting the excess or deficiency per cent. of spirit in any sample. Three sliding rules, which are used instead of the tables, likewise accompany the hydrometer. The exact temperature of the liquid should be taken previous to ascertaining the gravity, as the difference in temperature, if not corrected, would give, as the result, a weaker or stronger liquor than if the thermometer stood at 60° Fahr.

Fig. 50.



When excise officers use this instrument they are instructed to take the degree above the mercury, when it stands between any two degrees of the thermometer, as also the division below the surface of the liquid, when it stands between any two lines of the hydrometer, thus giving any advantage the difference occasions to the trader or manufacturer. The square weight or cap shows the difference between the weight of proof spirit and that of water, as described in the first clause of the hydrometer act, being one-twelfth part of the weight of the hydrometer when loaded with the weight 60. If this weight be placed on the top of the stem at A, and the hydrometer be loaded with the weight 60, it will sink in distilled water, at the temperature of 51° Fahr., to the proof point, P, marked on the narrow edge of the stem.

The following will serve as examples to show how the strength of the spirituous liquid is ascertained:—

Example 1.—Suppose the temperature of the solution to be 47°, and that the weight, 60, is required to sink the stem of the hydrometer to 8, which, when added to the weight 60, will give 68; then, under the temperature 47° Fahr., and in a line with the marginal indication, section 60, 68 is sought for, and carrying the eye along it is seen that the liquor is 10½ under proof.

Example 2.—If the stem of the instrument, when loaded with 50, sinks to 5, and the temperature, as shown by the thermometer, is 45° Fahr., then in the marginal section headed 50, 55—equal to the weight 50 and the indication on the divided stem—is found; and under the temperature 45°, the noted strength is 10·6 per cent. over proof.

The following are two out of fifty pages in a book given with the instrument:—

40° to 50° Temperature. Sikes' Alcoholometer I. Weight 50.

Indication.	Temperature of the spirits by Fahrenheit's thermometer.											Indication.
	40°	41°	42°	43°	44°	45°	46°	47°	48°	49°	50°	
50	19·2	18·9	18·6	18·3	18·0	17·7	17·3	17·0	16·7	16·4	16·1	50
·2	18·9	18·6	18·3	18·0	17·7	17·4	17·0	16·7	16·4	16·1	15·8	·2
·4	18·7	18·3	18·0	17·7	17·4	17·1	16·8	16·4	16·1	15·8	15·5	·4
·6	18·4	18·1	17·8	17·5	17·2	16·9	16·5	16·2	15·9	15·6	15·3	·6
·8	18·2	17·8	17·5	17·2	16·9	16·6	16·3	15·9	15·6	15·3	15·0	·8
51	17·9	17·5	17·2	16·9	16·6	16·3	16·0	15·6	15·3	15·0	14·7	51
·2	17·6	17·2	16·9	16·6	16·3	16·0	15·7	15·3	15·0	14·7	14·4	·2
·4	17·3	16·9	16·6	16·3	16·0	15·7	15·4	15·1	14·7	14·4	14·1	·4
·6	17·1	16·7	16·4	16·1	15·8	15·5	15·2	14·8	14·5	14·2	13·9	·6
·8	16·8	16·4	16·1	15·8	15·5	15·2	14·9	14·6	14·2	13·9	13·6	·8
52	16·5	16·1	15·8	15·5	15·2	14·9	14·6	14·3	13·9	13·6	13·3	52
·2	16·2	15·8	15·5	15·2	14·9	14·6	14·3	14·0	13·6	13·3	13·0	·2
·4	15·9	15·5	15·2	14·9	14·6	14·3	14·0	13·7	13·3	13·0	12·7	·4
·6	15·6	15·3	15·0	14·7	14·4	14·1	13·7	13·4	13·1	12·8	12·5	·6
·8	15·3	15·0	14·7	14·4	14·1	13·8	13·4	13·1	12·8	12·5	12·2	·8
53	15·0	14·7	14·4	14·1	13·8	13·5	13·1	12·8	12·5	12·2	11·9	53
·2	14·7	14·4	14·1	13·8	13·5	13·2	12·8	12·5	12·2	11·9	11·6	·2
·4	14·4	14·1	13·8	13·5	13·2	12·9	12·5	12·2	11·9	11·6	11·3	·4
·6	14·2	13·9	13·6	13·3	13·0	12·7	12·3	12·0	11·7	11·4	11·1	·6
·8	13·9	13·6	13.3	13·0	12·7	12·4	12·0	11·7	11·4	11·1	10·8	·8
54	13·6	13·3	13·0	12·7	12·4	12·1	11·7	11·4	11·1	10·8	10·5	54
·2	13·3	13·0	12·7	12·4	12·1	11·8	11·4	11·1	10·8	10·5	10·2	·2
·4	13·0	12·7	12·4	12·1	11·8	11·5	11·1	10·8	10·5	10·2	9·9	·4
·6	12·8	12·5	12·2	11·8	11·5	11·2	10·9	10·6	10·2	9·9	9·6	·6
·8	12·5	12·2	11·9	11·5	11·2	10·9	10·6	10·3	9·9	9·6	9·3	·8
55	12·2	11·9	11·6	11·2	10·9	10·6	10·3	10·0	9·6	9·3	9·0	55
·2	11·9	11·6	11·3	10·9	10·6	10·3	10·0	9·7	9·3	9·0	8·7	·2
·4	11·6	11·3	11·0	10·6	10·3	10·0	9·7	9·4	9·0	8·7	8·4	·4
·6	11·3	11·0	10·7	10·4	10·1	9·7	9·4	9·1	8·8	8·5	8·1	·6
·8	11·0	10·7	10·4	10·1	9·8	9·4	9·1	8·8	8·5	8·2	7·8	·8
56	10·7	10·4	10·1	9·8	9·5	9·1	8·8	8·5	8·2	7·9	7·5	56
·2	10·4	10·1	9·8	9·5	9·2	8·8	8·5	8·2	7·9	7·6	7·2	·2
·4	10·1	9·8	9·5	9·2	8·9	8·5	8·2	7·9	7·6	7·3	6·9	·4
·6	9·9	9·6	9·3	9·0	8·6	8·3	7·9	7·6	7·3	7·0	6·7	·6
·8	9·6	9·3	9·0	8·7	8·3	8·0	7·6	7·3	7·0	6·7	6·4	·8
57	9·3	9·0	8·7	8·4	8·0	7·7	7·3	7·0	6·7	6·4	6·1	57
·2	9·0	8·7	8·4	8·1	7·7	7·4	7·0	6·7	6·4	6·1	5·8	·2
·4	8·7	8·4	8·1	7·8	7·4	7·1	6·7	6·4	6·1	5·8	5·5	·4
·6	8·4	8·1	7·8	7·5	7·2	6·8	6·5	6·1	5·8	5·5	5·2	·6
·8	8·1	7·8	7·5	7.2	6·9	6·5	6·2	5·8	5·5	5·2	4·9	·8
58	7·8	7·5	7·2	6·9	6·6	6·2	5·9	5·5	5·2	4·9	4·6	58
·2	7·5	7·2	6·9	6·6	6·3	5·9	5·6	5·2	4·9	4·6	4·3	·2
·4	7·2	6·9	6·6	6·3	6·0	5·6	5·3	4·9	4·6	4·3	4·0	·4
·6	6·9	6·6	6·3	5·9	5·7	5·3	5·0	4·7	4·3	4·0	3·7	·6
·8	6·6	6·3	6·0	5·6	5·4	5·0	4·7	4·4	4·0	3·7	3·4	·8
59	6·3	6·0	5·7	5·3	5·1	4·8	4·4	4·1	3·7	3·4	3·1	59
·2	6·0	5·7	5·4	5·0	4·8	4·4	4·1	3·8	3·4	3·1	2·8	·2
·4	5·7	5·4	5·1	4·7	4·5	4·1	3·8	3·5	3·1	2·8	2·5	·4
·6	5·4	5·1	4·8	4·4	4·1	3·8	3·5	3·2	2·8	2·5	2·1	·6
·8	5·1	4·8	4·5	4·1	3·8	3·5	3·2	2·9	2·5	2·2	1·8	·8
60	4·8	4·5	4·2	3·8	3·5	3·2	2·9	2·6	2·2	1·9	1·5	60
Indication.	40°	41°	42°	43°	44°	45°	46°	47°	48°	49°	50°	Indication.
	Temperature of the spirits by Fahrenheit's thermometer.											

WEIGHT 60. SIKES' ALCOHOLOMETER II. TEMPERATURE 40° TO 50°.

Indication.	Temperature of the spirit by Fahrenheit's thermometer.											Indication.
	40°	41°	42°	43°	44°	45°	46°	47°	48°	49°	50°	
60	4·8	4·5	4·2	3·8	3·5	3·2	2·9	2·6	2·2	1·9	1·5	60
·2	4·5	4·2	3·9	3·5	3·2	2·9	2·6	2·3	1·9	1·6	1·2	·2
·4	4·2	3·9	3·6	3·2	2·9	2·6	2·3	2·0	1·6	1·3	·9	·4
·6	3·9	3·6	3·3	2·9	2·6	2·3	2·0	1·7	1·3	1·0	·6	·6
·8	3·6	3·3	3·0	2·6	2·3	2·0	1·7	1·4	1·0	·7	·3	·8
61	3·3	3·0	2·7	2·3	2·0	1·7	1·4	1·1	·7	·4	·0	61
·2	3·0	2·7	2·4	2·0	1·7	1·4	1·1	·8	·4	·1	·3	·2
·4	2·7	2·4	2·1	1·7	1·4	1·1	·8	·5	·1	·2	·6	·4
·6	2·4	2·1	1·8	1·4	1·1	·8	·4	·1	·3	·6	·9	·6
·8	2·1	1·8	1·5	1·1	·8	·5	·1	·2	·6	·9	1·2	·8
62	1·8	1·5	1·2	·8	·5	·2	·2	·5	·9	1·2	1·5	62
·2	1·5	1·2	·9	·5	·2	·1	·5	·8	1·2	1·5	1·8	·2
·4	1·2	·9	·6	·2	·1	·4	·8	1·1	1·5	1·8	2·1	·4
·6	·8	·5	·2	·2	·5	·8	1·1	1·5	1·8	2·2	2·5	·6
·8	·5	·2	·1	·5	·8	1·1	1·4	1·8	2·1	2·5	2·8	·8
63	·2	·1	·4	·8	1·1	1·4	1·7	2·1	2·4	2·8	3·1	63
·2	·1	·4	·7	1·1	1·4	1·7	2·0	2·4	2·7	3·1	3·4	·2
·4	·4	·7	1·0	1·4	1·7	2·1	2·4	2·7	3·0	3·4	3·7	·4
·6	·8	1·1	1·4	1·8	2·1	2·4	2·7	3·1	3·4	3·8	4·1	·6
·8	1·1	1·4	1·7	2·1	2·4	2·8	3·1	3·4	3·7	4·1	4·4	·8
64	1·4	1·7	2·0	2·4	2·7	3·1	3·4	3·7	4·0	4·4	4·1	64
·2	1·7	2·0	2·3	2·7	3·0	3·4	3·7	4·0	4·3	4·7	5·6	·2
·4	2·0	2·3	2·6	3·0	3·3	3·7	4·1	4·4	4·7	5·1	5·4	·4
·6	2·4	2·7	3·0	3·4	3·7	4·1	4·4	4·7	5·0	5·4	5·7	·6
·8	2·7	3·0	3·3	3·7	4·0	4·4	4·8	5·1	5·4	5·8	6·1	·8
65	3·0	3·3	3·6	4·0	4·3	4·7	5·1	5·4	5·7	6·1	6·4	65
·2	3·3	3·6	3·9	4·3	4·6	5·0	5·4	5·7	6·0	6·4	6·7	·2
·4	3·6	4·0	4·3	4·7	5·0	5·4	5·7	6·1	6·4	6·8	7·1	·4
·6	4·0	4·3	4·6	5·0	5·3	5·7	6·1	6·4	6·7	7·1	7·4	·6
·8	4·3	4·7	5·0	5·4	5·7	6·1	6·4	6·8	7·1	7·5	7·8	·8
66	4·6	5·0	5·3	5·7	6·0	6·4	6·7	7·1	7·4	7·8	8·1	66
·2	5·0	5·3	5·7	6·0	6·3	6·7	7·0	7·4	7·7	8·1	8·4	·2
·4	5·3	5·7	6·0	6·4	6·7	7·1	7·4	7·8	8·1	8·5	8·8	·4
·6	5·7	6·0	6·4	6·7	7·0	7·4	7·7	8·1	8·4	8·8	9·1	·6
·8	6·0	6·4	6·7	7·1	7·4	7·8	8·1	8·5	8·8	9·2	9·5	·8
67	6·4	6·7	7·1	7·4	7·7	8·1	8·4	8·8	9·1	9·5	9·8	67
·2	6·7	7·0	7·4	7·7	8·0	8·4	8·7	9·1	9·4	9·8	10·1	·2
·4	7·1	7·4	7·8	8·1	8·4	8·8	9·1	9·5	9·8	10·2	10·5	·4
·6	7·4	7·7	8·1	8·4	8·7	9·1	9·4	9·8	10·1	10·5	10·8	·6
·8	7·8	8·1	8·5	8·8	9·1	9·5	9·8	10·2	10·5	10·9	11·2	·8
68	8·1	8·4	8·8	9·1	9·4	9·8	10·1	10·5	10·8	11·2	11·5	68
·2	8·5	8·8	9·1	9·4	9·8	10·2	10·5	10·9	11·2	11·6	11·9	·2
·4	8·8	9·1	9·5	9·8	10·1	10·5	10·8	11·2	11·5	11·9	12·2	·4
·6	9·2	9·5	9·8	10·1	10·5	10·9	11·2	11·6	11·9	12·3	12·6	·6
·8	9·5	9·8	10·2	10·5	10·8	11·2	11·5	11·9	12·2	12·6	12·9	·8
69	9·9	10·2	10·5	10·8	11·2	11·6	11·9	12·3	12·6	13·0	13·3	69
·2	10·3	10·6	10·9	11·2	11·6	12·0	12·3	12·7	13·0	13·4	13·7	·2
·4	10·6	10·9	11·2	11·5	11·9	12·3	12·6	13·0	13·3	13·7	14·0	·4
·6	11·0	11·3	11·6	11·9	12·3	12·7	13·0	13·4	13·7	14·1	14·4	·6
·8	11·3	11·6	11·9	12·2	12·6	13·0	13·3	13·7	14·0	14·4	14.7	·8
70	11·7	12·0	12·3	12·6	13·0	13·4	13·7	14·1	14·4	14·8	15·1	70
Indication.	40°	41°	42°	43°	44°	45°	46°	47°	48°	49°	50°	Indication.
	Temperature of the spirit by Fahrenheit's thermometer.											

A modification of Sikes' hydrometer has been constructed of glass, and is in the shape of an ordinary hydrometer, the stem being divided into degrees from 1 to 100; it carries a small delicate spirit thermometer in the bulb, to which a scale is affixed, having references from 0° to 12°, corresponding to Fahrenheit's scale from 32° to 80°. The temperature of the alcoholic liquors is indicated by the small thermometer; and the calculations in the tables accompanying the instrument are made to accord with these numbers. Tables are supplied with the hydrometer, which are headed by the degrees and half degrees of the thermometric scale; and the corresponding amount of spirit over or under proof at the respective degree of the table is placed opposite each degree of the hydrometer.

When the instrument is used to ascertain the value of a liquid, the degree of immersion and also that of the thermometer are noted; on referring to the table headed by the observed temperature, the percentage of spirit over or under proof is found opposite the degree to which the hydrometer sunk in the liquid.

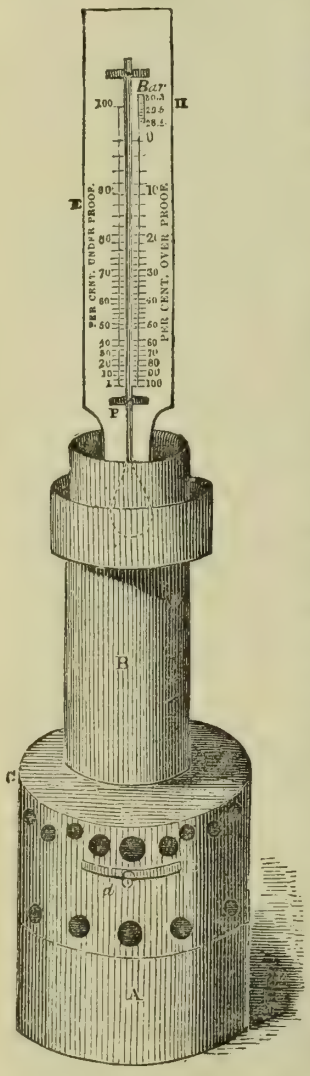
By Sikes' hydrometer, the specific gravity of the spirit indicating proof strength is ·9200. URE has constructed a table, appended below, wherein the specific gravity corresponds to the strength noted by the hydrometer, whether over or under proof strength.

CORRESPONDENCE BETWEEN THE SPECIFIC GRAVITIES AND PER CENTS. OF ALCOHOL OVER PROOF AT 60° FAHRENHEIT.

Specific gravity.	Per cent. over proof.	Specific gravity.	Per cent. over proof.	Specific gravity.	Per cent. over proof.	Specific gravity.	Per cent. over proof.	Specific gravity.	Per cent. over proof.	Specific gravity.	Per cent. under proof.	Specific gravity.	Per cent. under proof.
0·8156	67·0	0·8410	54·2	0·8657	39·3	0·8912	21·9	0·9178	1·9	0·9445	21·9	0·9722	58·3
8160	66·8	8413	54·1	8660	39·1	8915	21·7	9182	1·6	9448	22·2	9726	59·0
8163	66·6	8417	53·9	8664	38·9	8919	21·4	9185	1·3	9452	22·7	9730	59·7
8167	66·5	8420	53·7	8667	38·7	8922	21·2	9189	1·0	9456	23·1	9734	60·4
8170	66·3	8424	53·5	8671	38·4	8926	20·9	9192	0·7	9460	23·5	9738	61·1
8174	66·1	8427	53·3	8674	38·2	8930	20·6	9196	0·3	9464	23·9	9742	61·8
8178	65·6	8431	53·1	8678	38·0	8933	20·4	9200	Proof.	9468	24·3	9746	62·5
8181	65·8	8434	52·9	8681	37·8	8937	20·1	Under	proof.	9472	24·7	9750	63·2
8185	65·6	8438	52·7	8685	37·6	8940	19·9	9204	0·3	9476	25·1	9754	63·9
8188	65·5	8441	52·5	8688	37·3	8944	19·6	9207	0·6	9480	25·5	9758	64·6
8192	65·3	8445	52·3	8692	37·1	8948	19·3	9210	0·9	9484	25·9	9762	65·3
8196	65·1	8448	52·1	8695	36·9	8951	19·1	9214	1·3	9488	26·3	9766	66·0
8199	65·0	8452	51·9	8699	36·7	8955	18·8	9218	1·6	9492	26·7	9770	66·7
8203	64·8	8455	51·7	8702	36·4	8959	18·6	9222	1·9	9496	27·1	9774	67·4
8206	64·7	8459	51·5	8706	36·2	8962	18·3	9226	2·2	9499	27·5	9778	68·0
8210	64·5	8462	51·3	8709	35·9	8966	18·0	9229	2·5	9503	28·0	9782	68·7
8214	64·3	8465	51·1	8713	35·7	8970	17·7	9233	2·8	9507	28·4	9786	69·4
8218	64·1	8469	50·9	8716	35·5	8974	17·5	9237	3·1	9511	28·8	9790	70·1
8221	61·0	8472	50·7	8720	35·2	8977	17·2	9241	3·4	9515	29·2	9794	70·8
8224	63·8	8476	50·5	8723	35·0	8981	16·9	9244	3·7	9519	29·7	9798	71·4
8227	63·6	8480	50·3	8727	34·7	8985	16·6	9248	4·0	9522	30·1	9802	72·1
8231	63·4	8482	50·1	8730	34·5	8989	16·4	9252	4·4	9526	30·6	9806	72·8
8234	63·2	8486	49·9	8734	34·3	8992	16·1	9255	4·7	9530	31·0	9810	73·5
8238	63·1	8490	49·7	8737	34·1	8996	15·9	9259	5·0	9534	31·4	9814	74·1
8242	62.9	8493	49·5	8741	33·8	9000	15·6	9263	5·3	9539	31·1	9818	74·8
8245	62·7	8496	49·3	8744	33·6	9004	15·3	9267	5·7	9542	32·3	9822	75·4
8249	62·5	8499	49·1	8748	33·4	9008	15·0	9270	6·0	9546	32·8	9826	76·1
8252	62·3	8503	48·9	8751	33·2	9011	14·8	9274	6·4	9550	33·2	9830	76·7
8256	62·2	8506	48·7	8755	32·9	9015	14·5	9278	6·7	9553	33·7	9834	77·3
8259	62·0	8510	48·5	8758	32·7	9019	14·2	9282	7·0	9557	34·2	9838	78·0
8263	61·8	8513	48.3	8762	32·4	9023	13·9	9286	7·3	9561	34·7	9842	78·6
8266	61·6	8516	48·0	8765	32·2	9026	13·6	9291	7·7	9565	35·1	9846	79·2
8270	61·4	8520	47·8	8769	32·0	9030	13·4	9295	8·0	9569	35·6	9850	79·8
8273	61·3	8523	47·6	8772	31·7	9034	13·1	9299	8·3	9573	36·1	9854	80·4
8277	61·1	8527	47·4	8776	31·5	9038	12·8	9302	8·6	9577	36·6	9858	81·1
8280	60·9	8530	47·2	8779	31·2	9041	12·5	9306	9·0	9580	37·1	9862	81·7
8284	60·7	8533	47·0	8783	31·0	9045	12·2	9310	9·3	9584	37·6	9866	82·3
8287	60·5	8537	46·8	8786	30·8	9049	12·0	9314	9·7	9588	38·1	9870	82·9
8291	60·4	8540	46·6	8790	30·5	9052	11·7	9318	10·0	9592	38·6	9874	83·5
8294	60·2	8543	46·4	8793	30·3	9056	11·4	9322	10·3	9596	39·1	9878	84·0
8298	60·0	8547	46·2	8797	30·0	9060	11·1	9326	10·7	9599	39·6	9882	84·6
8301	59·8	8550	46·0	8800	29·8	9064	10·8	9329	11·0	9603	40·1	9886	85·2
8305	59·6	8553	45·8	8804	29·5	9067	10·6	9332	11·4	9607	40·6	9890	85·8
8308	59·5	8556	45·6	8807	29·3	9071	10·3	9337	11·7	9611	41·1	9894	86·3
8312	59·3	8560	45·4	8811	29·0	9075	10·0	9341	12·1	9615	41·7	9898	86·9
8315	59·1	8563	45·2	8814	28·8	9079	9·7	9345	12·4	9619	42·2	9902	87·4
8319	58·9	8566	45·0	8818	28·5	9082	9·4	9349	12·8	9623	42·8	9906	88·0
8322	58·7	8570	44·8	8822	28·3	9085	9·2	9353	13·1	9627	43·3	9910	88·5
8326	58·6	8573	44·6	8825	28·0	9089	8·9	9357	13·5	9631	43·9	9914	89·1
8329	58·4	8577	44·4	8829	27·8	9093	8·6	9360	13·9	9635	44·4	9918	89·6
8333	58·2	8581	44·2	8832	27·5	9097	8·3	9364	14·2	9638	45·0	9922	90·2
8336	58·0	8583	43·9	8836	27·3	9100	8·0	9368	14·6	9642	45·5	9926	90·7
8340	57·8	8587	43·7	8840	27·0	9104	7·7	9372	14·9	9646	46·1	9930	91·2
8344	57·7	8590	43·5	8843	26·8	9107	7·4	9376	15·3	9650	46·7	9934	91·7
8347	57·5	8594	43·3	8847	26·5	9111	7·1	9380	15·7	9654	47·3	9938	92·3
8351	57·3	8597	43·1	8850	26·3	9115	6·8	9384	16·0	9657	47·9	9942	92·8
8354	57·1	8601	42·8	8854	26·0	9118	6·5	9388	16·4	9661	48·5	9946	93·3
8358	56·9	8604	42·6	8858	25·8	9122	6·2	9392	16·7	9665	49·1	9950	93·8
8362	56·8	8608	42·4	8861	25·5	9126	5·9	9396	17·1	9669	49·7	9954	94·3
8365	56·6	8611	42·2	8865	25·3	9130	5·6	9399	17·5	9674	50·3	9958	94·9
8369	56·4	8615	42·0	8869	25·0	9134	5·3	9403	17·8	9677	51·0	9962	95·4
8372	56·2	8618	41·7	8872	24·8	9137	5·0	9407	18·2	9681	51·6	9966	95·9
8376	56·0	8622	41·5	8876	24·5	9141	4·8	9411	18·5	9685	52·2	9970	96·4
8379	55·9	8625	41·3	8879	24·3	9145	4·5	9415	18·9	9689	52·9	9974	96·8
8383	55·7	8629	41·1	8883	24·0	9148	4·2	9419	19·3	9693	53·3	9978	97·3
8386	55·5	8632	40·9	8886	23·8	9152	3·9	9422	19·7	9697	54·2	9982	97·7
8390	55·3	8636	40·6	8890	23·5	9156	3·6	9426	20·0	9701	54·8	9986	98·2
8393	55·1	8639	40·4	8894	23·2	9159	3·3	9430	20·4	9705	55·5	9990	98·7
8396	55·0	8643	40·2	8897	23·0	9163	3·0	9434	20·8	9709	56·2	9993	99·1
8400	54·8	8646	40·0	8901	22·7	9167	2·7	9437	21·2	9713	56·9	9997	99·6
8403	54·6	8650	39·8	8904	22·5	9170	2·4	9441	21·6	9718	57·6	1·0000	100·0
8407	54·4	8653	39·6	8908	22·2	9174	2·1						

Although it had long been known that the boiling point of water was raised by the solution in it of neutral salts and other bodies, the application of this fact to the determination of the quantity of alcohol in spirituous liquors was reserved for the Abbé Brossard-Vidal, of Toulon, who ascertained that the boiling point of such liquors was in direct proportion to the quantity of alcohol they contained, irrespective of any amount of saline ingredients present in them. When such salts are added to dilute alcohol as abstract a portion of the water, the boiling point of the solution is lowered, instead of the reverse being the case.

Fig. 51.



This principle also formed the basis of Field's alcoholometer, for the determination of the amount of spirit in every description of alcoholic liquor at any period after fermentation, for which he obtained a patent in 1847. It consisted originally of a spirit lamp, surmounted by a boiler containing the liquid to be examined, and a large cylindrical glass bulb containing mercury, and having an upright stem, whose calibre was such as to allow the expansion of the mercury to elevate a small glass float which rested on its surface. This float was connected by a thread with a similar bead, which hung in the open air; the thread passed over a pulley which, turning with the motion of the beads, caused the index to move along the circular graduated scale. This instrument was much improved by Ure, who introduced, instead of the cylindrical bulb and beads, a thermometer attached to a graduated scale. Fig. 51 shows the improved instrument.

A is the spirit lamp, surrounded by an outer coating containing cold water for keeping the lamp cool, should many successive experiments be required; B is the boiler, which fits into the cage, C, in the case of the lamp; a damper, *d*, regulates the heat of the lamp; E is the thermometer, which has a very small bore. The bottom of the scale on the ebullition thermometer is marked P, for proof, on the left side, and 100—proof spirit—on the right side. It corresponds with 178·6 Fahr. nearly, or the boiling point of alcohol, spec. grav. ·920.

From the mean of a great number of experiments, Ure drew up the following table, which shows the boiling point of alcohol of various specific gravities:—

Temperature Fahr.	Specific gravity.		
178·5	0·9200	—	Proof.
179·75	0·9321	10	Under proof.
180·4	0·9420	20	"
182·01	0·9516	30	"
183·40	0·960	40	"
185·6	0·9665	50	"
189 0	0·9729	60	"
191·8	0·9786	70	"
196·4	0·9850	80	"
202·0	0·992	90	"

When the spirit is above proof, the variation of its boiling point is so small that a strictly accurate result cannot be obtained: proof spirit, or spirit approaching to that strength, is more accurately tested by diluting it with its own bulk of water before ascertaining the strength, and then doubling the result. Another source of error pointed out by Ure, is the elevation of the boiling point when the liquor is kept heated for any length of time; this is, however, obviated by the addition of common salt to the solution in the boiler of the apparatus. In order to côrrect the difference arising from a higher or lower pressure of the atmosphere, distilled water should be boiled in the apparatus, and the temperature noted; for the boiling point of the alcoholic solutions will vary as that of the water, when the pressure of the atmosphere is greater or less. In order to correct this source of error, a subsidiary barometrical scale, H, is attached to the thermometer, F. The method of using this alcoholometer is as follows:—

The lamp, A, is lighted; B is filled to about one inch from the top with the liquid to be examined, to which a paper of common salt is added, and the whole is then placed on the lamp, A; and lastly, the thermometer, E, is fixed to the scale, with its bulb immersed in the liquid. Before commencing general operations for the day, the boiler, B, is filled with water, and boiled; if the column of mercury remains at 29·5, which is placed opposite to 100 on the scale at the left hand—the mean boiling point of water—no correction is required to be made; but if it stands higher or lower than this figure, the various boiling points of the samples bear reference to this. In testing the solutions, when the mercury begins to rise out of the bulb of the thermometer, the damper is to be pushed in midway into the groove to lower the heat. As the liquid boils freely, the mercury in the tube will become stationary, and the figure on the left will indicate the percentage under proof, while that on the right will show the percentage over proof. Field's alcoholometer only tells the quantity of alcohol, but an auxiliary experiment with the hydrometer will readily give the specific gravity, and upon reference to Table I., the amount of saccharine and extractive matter can be ascertained. In testing wines, the specific gravity of the liquid is first taken, then the boiling point ascertained by the alcoholometer, and the corresponding specific gravity deducted from that previously found by the hydrometer; the difference will, upon referring to Table II., show the quantity of extractive and saccharine matter in 100 gallons of the liquid. For example, if the specific gravity by the hydrometer be ·989, and that by the alcoholometer shows the presence of alcohol of $69\frac{6}{10}$, whose specific gravity is ·979 by the tables, deduct the latter gravity from the gravity of the bulk, or ·989, and a difference of ten remains, which number, upon reference to Table II., will give 25 lbs. of saccharine and extractive matter in 100 gallons, combined with $30\frac{4}{10}$ gallons of proof spirit. Should the barometer be above or below the standard 29·5, the thermometer scale will then only show the apparent strength, and reference must be had to the small ivory indicator, it being the counterpart of the barometrical scale of the thermometer; thus, if the barometer indicate 30, place 30 of the indicator against the boiling point of the liquid, and opposite the line of 29·5 will be found the true strength.

Example 1.—Barometer at 30.—Suppose the mercury to stop at the same point, 72 U.P.; place 30 of the indicator against 72 on the thermometer, and the line 29·5 will cut 69·6 U.P., the true percentage.

Example 2.—Barometer at 29.—Suppose the mercury to stop at the same point, 72 U.P.; place 29 of the indicator against 72 on the thermometer, and the line 29·5 will cut 74·3 U.P., the true strength.

To ascertain the strength of malt liquors and their respective values, the instrument has been furnished with a glass saccharometer, testing glass, and slide rule. Commence by charging the test glass with the liquid, then insert the saccharometer to ascertain the present gravity or density per barrel, the number at which it floats indicates the number of pounds per barrel the liquor is heavier than water:—

Example 1.—Suppose the saccharometer to float at the figure 8, which would indicate 8 lbs. per barrel; then submit the liquid to the boiling test, with an addition of salt to arrest the mercury at the true boiling point of the liquid; now, suppose it should show—the barometrical difference being accounted for—90 U.P., that would be equivalent to 10 per cent. of proof alcohol. Refer to the slide scale, and place A on the slide against 10 on the upper line of figures, and facing B on the lower line will be 18, showing that 18 lbs. per barrel have been decomposed to constitute that percentage of spirit; then, by adding 18 lbs. to the present 8 lbs. per barrel, the result will be 26 lbs., the original weight of the wort after leaving the copper.

Example 2.—The saccharometer marks 10 lbs. per barrel, and at the boiling point it indicates 88 U.P., equivalent to 12 gallons of proof spirit per cent.; place A against 12, and opposite B will be $21\frac{1}{2}$, the number of lbs. per barrel, which, when added to the 10 lbs. present, will give a total of $31\frac{1}{2}$ lbs.

To ascertain the relative value.—Suppose the price of the 26 lbs. beer to be 36*s.* per barrel, and the $31\frac{1}{2}$ lbs. beer to be 40*s.*—to ascertain which beer will be the cheaper, place 26 on the opposite side of the rule against 36, and opposite $31\frac{1}{2}$ lbs. will be 43*s.* 7*d.*, showing that the latter beer is cheaper by 3*s.* 7*d.* per barrel. By this instrument the quantity of spirit per cent. in distiller's wort, whether it be in progress of fermentation or ready for the still, is indicated, the only difference being in the allowances in the sliding rule. Saccharometers applicable to the foregoing rules for beer, ale, &c., have been adjusted at the temperature of 60° Fahr., and will be found sufficiently correct for general purposes; but where extreme minuteness is required, the variation of temperature must be taken into account, and for every 10 degrees of temperature above 60°, three-tenths of a pound must be added to the gross amount found by the slide rule; on the other hand, for every 10 degrees below 60°, three-tenths of a pound must be deducted.

For cordialized spirits the operation is different from that applied to the testing of beers, which have the alcohol generated in the wort. In cordials of every kind, the alcohol is the original, and the saccharine matter, or sugar, is an addendum. If 100 gallons of spirit are required of a given strength—say 50 per cent. under proof—50 gallons of proof spirit to which 50 gallons of water are added will be of this strength, and upon testing it by the alcoholometer it will be found as correct as by the hydrometer. But in cordializing spirit, the reverse is the case; for to the 50 gallons of spirit, proof strength, 50 gallons of sugar and water would be added, thereby rendering the hydrometer useless, excepting for taking the specific gravity of the bulk, and, according to the quantity of sugar present, so a relative quantity of water must have been displaced; and as the sugar has no reducing properties, the alcoholometer will only show the strength of the cordial in relation to the quantity of water contained in it, as the principle indicates, irrespective of the saccharine or extractive matter. Suppose, in making 100 gallons of cordial at 50 U.P., 3 lbs. of sugar are put to the gallon, or 300 lbs. to the 100 gallons, these 300 lbs. displacing 18·67 gallons of water, only 31·33 gallons of the water, instead of 50, have been applied; the sugar, without reducing properties, making up the bulk of 100 gallons, which is meant to represent 50 per cent. U.P.

The alcoholometer will only show at the full point of ebullition the alcoholic strength in relation to the water in 100 gallons of the mixture, or 35 per cent. U.P., leaving 15 per cent. to be accounted for in the bulk. As the quantity of sugar present must be determined before that percentage can be arrived at, a double object will be effected by so doing, namely, eliciting in all instances the quantity of sugar present, as well as the percentage of spirit to be accounted for.

Example.—Suppose the specific gravity of a cordial is 1·076, then submit the liquid to the boiling point, and having ascertained the percentage of alcohol—35 U.P.—the specific gravity of alcohol at that strength will be found to be 0·956; deduct 0·956 from the specific gravity of the bulk, or 1·076, and ·120 will remain; refer that to its amount in the head line of Table II., namely, 120, under which will be found 3, representing 3 lbs. of sugar to the gallon; and by running the eye down its column to opposite the alcoholic strength indicated—35 U.P.—will be found 14·9, representing the water displaced by the sugar, and which amount added to 35 per cent. ascertained, makes the total upon the bulk 49·9 per cent. U.P., with 3 lbs. of sugar to the gallon.

Table I., which shows the specific gravity on the bulk of the mixture, bears reference to the table following it—Table II. of the alcoholometer.

In estimating the density of various gins and cordials, suppose the specific gravity of the liquid is found to be ·957, and by the boiling point it proves to be 14 U.P., whose specific gravity is ·937; when this is deducted from the former—·957—the remainder is 20, under which in Table II. will be found ½, or one-half pound of sugar to the gallon; and on observing the opposite 14 U.P., 3·0 will be found, which, added to 14, makes the total on the bulk 17 per cent. U.P., with 50 pounds of sugar to the 100 gallons.

Table I.

Table of specific gravities by Sikes' hydrometer, adapted to Field's alcoholometer for cordialized spirits.

Temperature, 60°.—Specific gravity of water, 1·000°.

60		70		80		90		100		110		120		130		140		150		160		170		180	
Wt.	S. G.	Wt.	S. G.	Wt.	S. G.	Wt.	S. G.	Wt.	S. G.	Wt.	S. G.	Wt.	S. G.	Wt.	S. G.	Wt.	S. G.	Wt.	S. G.	Wt.	S. G.	Wt.	S. G.	Wt.	S. G.
60	922	70	942	80	961	90	981	100	1000	110	1020	120	1041	130	1063	140	1085	150	1107	160	1129	170	1152	180	1175
1	924	1	943	1	963	1	983	1	1002	1	1022	1	1044	1	1065	1	1087	1	1109	1	1131	1	1155	1	1178
2	926	2	945	2	965	2	985	2	1004	2	1024	2	1046	2	1067	2	1089	2	1111	2	1134	2	1157	2	1180
3	928	3	947	3	967	3	987	3	1006	3	1026	3	1048	3	1069	3	1091	3	1113	3	1136	3	1159	3	1182
4	930	4	949	4	969	4	989	4	1008	4	1029	4	1050	4	1071	4	1093	4	1116	4	1139	4	1162	4	1185
5	932	5	951	5	971	5	991	5	1010	5	1031	5	1052	5	1074	5	1096	5	1118	5	1141	5	1164	5	1187
6	934	6	953	6	973	6	993	6	1012	6	1033	6	1054	6	1076	6	1098	6	1120	6	1143	6	1166	6	1189
7	936	7	955	7	975	7	995	7	1014	7	1035	7	1056	7	1078	7	1100	7	1123	7	1145	7	1168	7	1191
8	938	8	957	8	977	8	997	8	1016	8	1037	8	1058	8	1080	8	1102	8	1125	8	1148	8	1171	8	1194
9	940	9	959	9	979	9	999	9	1018	9	1039	9	1061	9	1082	9	1104	9	1127	9	1150	9	1173	9	1196
70	942	80	961	90	981	100	1000	110	1020	120	1041	130	1063	140	1085	150	1107	160	1129	170	1152	180	1175	190	1199

Table II.

Table showing the lbs. of sugar per gallon in cordialized spirits, with the per centages to be added to the indicated strength, per the alcoholometer.

Difference of gravity. Lbs. of sugar per gallon.		10 4 oz. or 25 to 100.	15 6 oz. 37½ to 100.	20 8 oz. 50 to 100.	25 10 oz. 62½ to 100.	30 12 oz. 75 to 100.	35 14 oz. 87½ to 100.	40 1·0	45 oz. 1·2	50 oz. 1·4	Difference of gravity. Lbs. of sugar per gallon.	
Sp. grav. of spirit.	Per cent. of spirit.										Per cent. of spirit.	Sp. grav. of spirit.
920	Proof.	1·6	2·5	3·4	4·4	5·3	6·2	7·1	8·1	9·0	Proof.	920
923	2·5	1·6	2·5	3·3	4·3	5·2	6·1	6·9	7·8	8·8	2·5	923
926	5·	1·5	2·4	3·2	4·2	5·0	5·9	6·8	7·7	8·6	5·	926
929	7·5	1·5	2·3	3·2	4·1	4·9	5·8	6·6	7·5	8·4	7·5	929
932	10·	1·4	2·2	3·1	4·0	4·8	5·7	6·5	7·4	8·2	10·	932
935	12·5	1·4	2·2	3·1	3·9	4·7	5·5	6·3	7·2	8·0	12·5	935
938	15·	1·4	2·1	3·0	3·8	4·6	5·4	6·2	7·0	7·8	15·	938
940	17·5	1·3	2·1	2·9	3·7	4·5	5·3	6·0	6·8	7·6	17·5	940
943	20·	1·3	2·0	2·8	3·6	4·4	5·2	5·9	6·7	7·5	20·	943
945	22·5	1·3	2·0	2·7	3·5	4·3	5·0	5·7	6·5	7·3	22·5	945
948	25·	1·2	1·9	2·6	3·4	4·1	4·8	5·5	6·3	7·0	25·	948
950	27·5	1·2	1·9	2·5	3·3	4·0	4·7	5·3	6·1	6·8	27·5	950
952	30·	1·1	1·8	2·4	3·1	3·8	4·5	5·1	5·8	6·5	30·	952
954	32·5	1·1	1·7	2·3	3·0	3·6	4·3	4·8	5·5	6·2	32·5	954
956	35·	1·0	1·6	2·2	2·9	3·5	4·1	4·6	5·3	6·0	35·	956
958	37·5	1·0	1·6	2·1	2·8	3·4	3·9	4·4	5·1	5·8	37·5	958
960	40·	·9	1·5	2·0	2·7	3·2	3·8	4·3	4·9	5·5	40·	960
962	42·5	·9	1·5	2·0	2·6	3·1	3·6	4·1	4·7	5·3	42·5	962
964	45·	·9	1·4	1·9	2·5	3·0	3·5	4·0	4·6	5·1	45·	964
965	47·5	·8	1·4	1·9	2·4	2·9	3·4	3·9	4·4	4·9	47·5	965
967	50·	·8	1·3	1·8	2·3	2·8	3·3	3·8	4·3	4·8	50·	967
969	52·5	·7	1·2	1·7	2·2	2·6	3·1	3·6	4·1	4·5	52·5	969
970	55·	·7	1·2	1·6	2·0	2·4	2·9	3·4	3·8	4·2	55·	970
972	57·5	·6	1·1	1·5	1·9	2·2	2·7	3·1	3·5	3·9	57·5	972
973	60·	·6	1·0	1·4	1·8	2·1	2·5	2·9	3·3	3·6	60·	973
974	62·5	·6	1·0	1·3	1·7	2·0	2·4	2·7	3·1	3·5	62·5	974
976	65·	·5	·9	1·2	1·5	1·8	2·2	2·5	2·8	3·1	65·	976
977	67·5	·5	·8	1·1	1·4	1·7	2·0	2·3	2·6	2·9	67·5	977
979	70·	·4	·7	1·0	1·3	1·5	1·8	2·1	2·4	2·6	70·	979
980	72·5	·4	·7	·9	1·1	1·3	1·6	1·9	2·1	2·3	72·5	980
982	75·	·3	·6	·8	1·0	1·2	1·4	1·6	1·8	2·0	75·	982
983	77·5	·3	·5	·7	·9	1·0	1·2	1·4	1·6	1·8	77·5	983
984	80·	·2	·4	·6	·8	·9	1·0	1·2	1·4	1·6	80·	984
986	82·5	·2	·3	·5	·7	·8	·9	1·0	1·2	1·4	82·5	986
988	85·	·2	·2	·4	·6	·7	·8	·9	1·0	1·2	85·	988
990	87·5	·1	·2	·3	·5	·6	·7	·8	·9	1·0	87·5	990
992	90·	·1	·1	·2	·4	·5	·6	·7	·8	·9	90·	992
994	92·5	..	·1	·2	·3	·4	·5	·6	·7	·8	92·5	994
996	95·	..	..	·1	·2	·3	·4	·5	·6	·7	95·	996
998	97·5	..	..	..	·1	·2	·3	·4	·5	·6	97·5	998

Care must be taken that the mercury is entirely in the bulb of the thermometer before it is fixed to the stem; and salt must always be added when determining the boiling point, except in the case of water.

The instrument is very useful for testing the relative quantity of fruit and alcohol in normal wines.

FOWNES drew up a table of the value, in absolute alcohol, of spirits of different specific gravities, which is given below.

The table was formed synthetically; absolute alcohol and distilled water were weighed out in the required proportions, mixed in small closely-stopped bottles, and well shaken together. After standing three or four days, the mixtures were brought to the temperature of 60° Fahr. exactly, and their specific gravities determined with great care. When two or three days more had elapsed, the specific gravity was again taken, but in no case had any further contraction occurred. Neither was the specific gravity of a mixture, containing nearly equal parts alcohol and water, which had been so examined, changed by being inclosed in a strong accurately-stoppered bottle, and heated for some time to a temperature above its boiling point.

In this manner, every alternate number in the table —every even number—was obtained by direct experiment; the others were then incorporated.

TABLE OF THE PROPORTION BY WEIGHT

Of real or absolute alcohol contained in 100 parts of spirits of different specific gravities, at the temperature of 60° Fahr.

Specific gravity.	Per centage of alcohol.	Specific gravity.	Per centage of alcohol.	Specific gravity.	Per centage of alcohol.
·9991	0·5	·9511	34	·8769	68
·9981	1	·9490	35	·8745	69
·9965	2	·9470	36	·8721	70
·9947	3	·9452	37	·8696	71
·9930	4	·9434	38	·8672	72
·9914	5	·9416	39	·8649	73
·9898	6	·9396	40	·8625	74
·9884	7	·9376	41	·8603	75
·9869	8	·9356	42	·8581	76
·9855	9	·9335	43	·8557	77
·9841	10	·9314	44	·8533	78
·9828	11	·9292	45	·8508	79
·9815	12	·9270	46	·8483	80
·9802	13	·9249	47	·8459	81
·9789	14	·9228	48	·8434	82
·9778	15	·9206	49	·8408	83
·9766	16	·9184	50	·8382	84
·9753	17	·9160	51	·8357	85
·9741	18	·9135	52	·8331	86
·9728	19	·9113	53	·8305	87
·9716	20	·9090	54	·8279	88
·9704	21	·9069	55	·8254	89
·9691	22	·9047	56	·8228	90
·9678	23	·9025	57	·8199	91
·9665	24	·9001	58	·8172	92
·9652	25	·8979	59	·8145	93
·9638	26	·8956	60	·8118	94
·9623	27	·8932	61	·8089	95
·9609	28	·8908	62	·8061	96
·9593	29	·8886	63	·8031	97
·9578	30	·8863	64	·8001	98
·9560	31	·8840	65	·7969	99
·9544	32	·8816	66	·7938	100
·9528	33	·8793	67		

The contraction of volume suffered by various mixtures of alcohol and water, may be rendered obvious by comparing the actual specific gravities of such mixtures with their calculated mean densities. In Fig. 52, on the next page, in which the vertical lines represent the percentage of alcohol by weight, and the horizontal lines the specific gravities, the calculated mean specific gravities of the mixtures are seen to form a straight diagonal line from corner to corner, while the actual densities form an irregular curve with upward convexity, rising quickly to its maximum deviation at 30 per cent., running almost parallel with the other line to 50 per cent., and thence declining until it reaches the extremity of the scale.

SILBERMANN holds that the various means employed for ascertaining the respective quantities of alcohol and water in mixtures of those liquids possess many disadvantages. The distillation process is rarely employed, on account of the great skill required in its application, and the length of time the operation demands before the results are arrived at. This method, at best, is only applied where accurate and scientific truth is required, irrespective of delay and toil. The density test is open to error on account of extractive matters being present, which render the specific gravity of the impregnated liquid higher than that of alcohol, and thus prevent the true amount of spirit from being determined with strict accuracy; hence the excise duty is, in consequence, evaded. Wines tested by the density process only indicate about one-half their strength; and for this reason GAY-LUSSAC combines, with the use of his alcoholometric areometer, the distillation test.

He objects likewise to the boiling test of Field's hydrometer, that liquids may be heated beyond their boiling point without ebullition, and that the thermometer, even when immersed in the liquid, may under certain circumstances stand several degrees above the real temperature, which would give rise to a difference in result of four alcoholometric degrees for every such extra indication. He also considers that the barometric variations should be taken into account in some better way. SILBERMANN'S arrangement to obviate these evils is based upon the dilatation of the alcoholic liquid. It is well known that between 32° and 212° Fahr. (0° and 100° C.), the dilatation of alcohol is triple that of water. This is much greater between 77° and 122° Fahr. (25° and 50° C.)—and may thus be demonstrated:—Pour water at 25° C. into a thermometer tube, so as to fill the reservoir, and a small portion of the tube up to a certain mark; then, on heating the thermometer to 50° C. the water will rise a certain distance above the mark, and let this point be scratched on the tube; now, if the same quantity of pure alcohol, also at 25° C., be substituted for the water, and heated to the temperature of 50° C., it will be found to have risen three and a half times higher than the water. Any mixture of alcohol and water, on being treated in the same way, will be found to have a mean point of dilatation between these two, and will be nearer the one or the other, according as either liquid preponderates. If, therefore, a series of mixtures of alcohol and water be made, beginning with—

Water 100 parts,	......	Alcohol	0 parts;
do. 99 "	....	do.	1 "
do. 98 "	....	do.	2 "

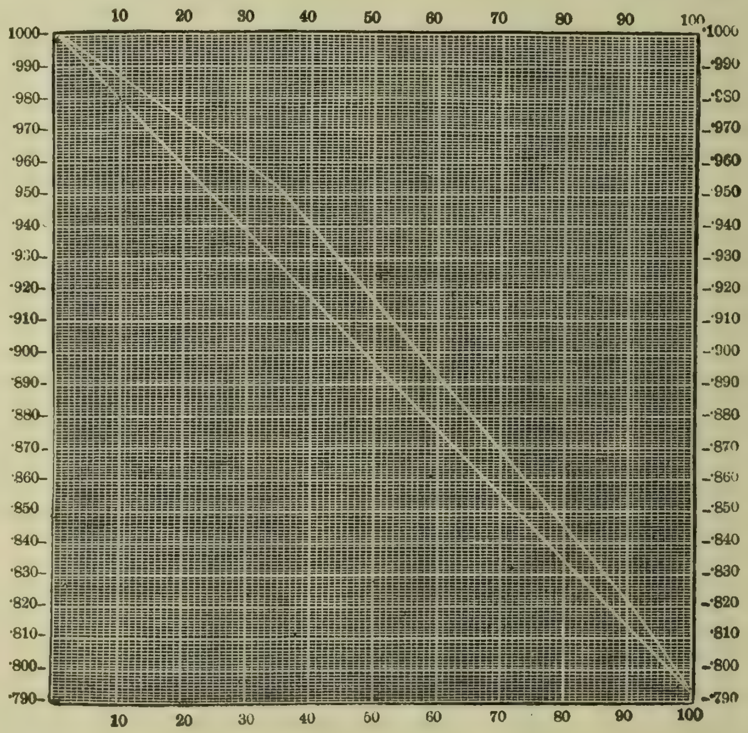
and so on up to pure alcohol; and their several points of elevation at the respective temperatures (25° to 50° C.), be carefully marked on the tube, a complete centesimal alcoholometric scale will be produced, which will indicate the quantity of alcohol contained in any mixture of alcohol and water, by introducing it at 25° C. and heating it to 50° C.

The same process may be employed with regard to any other two liquids having points of dilatation differing between those of alcohol and water; but it will be understood that the same scale will not serve for more than one mixture. To adapt this principle to the ordinary purposes of alcoholometric measurement, SILBERMANN constructed a thermometer in a peculiar manner, thereby forming an instrument which he named a *dilatometer*, Fig 53.

The form and arrangement of this apparatus are these:—A large bulb tube, A, of the form of a hydrometer, but tapering at the bottom and open at the top, is fixed to a metal plate, to which a thermometer, C, is also attached. The thermometer is graduated from 77° to 122° Fahr. (25° to 50° C.). Both the thermometer and bulb of the apparatus, A, are immersed in the liquor to be tested; the former to show the temperature, and the latter to ascertain the expansion of the liquid when it is heated from 25° to 50° C. The expansion of distilled water between the extreme degrees of the thermometer is marked on the stem of A by the figures 25 and 50; from the latter the scale of degrees from 1 to 100 appended to the stem of the apparatus commences, and by it the expansion of the alcoholic liquors is ascertained, when such liquors are heated from 25° to 50° C. A valve of cork or india-rubber closes the tapering end of A; this valve is attached to a rod, *b b*, fastened to the supporting plate and connected to a spring, B. To cause the liquid under examination to flow, the spring valve is depressed by turning a screw of four threads for the purpose of giving a quick motion, fitting in the upper part of the rod, and by reversing the motion of the screw the thermometer is closed; sometimes the rod may be made to terminate in a flattened end or cap, as the figure represents, and is moved by pressing it with the finger. As the liquids are often impregnated with air or gas, it is found necessary, before testing, to remove it; the best method of effecting this is by means of a vacuum, which may be produced by the use of a small leather piston, E, working in the tube of the thermometer. This piston serves first, by suction, to fill the thermometer from below; and then, the lower part being closed, by two or three strokes to separate the air from the liquid. To effect the withdrawal of the piston without any shock, so as not to divide the column abruptly, the piston-rod is made hollow throughout; the operator, having wetted his finger, applies it to the top of the piston-rod, in order to create a vacuum as he draws

Fig. 52.

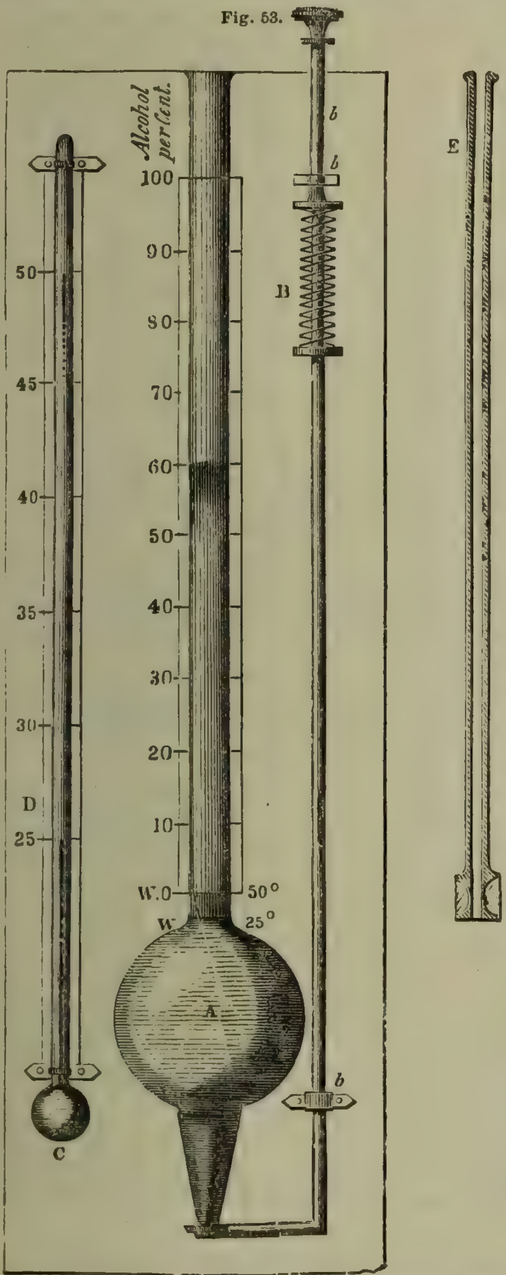
COMPARISON OF MEAN AND ACTUAL SPECIFIC GRAVITIES OF VARIOUS MIXTURES OF ALCOHOL AND WATER.



up the piston; he then withdraws it to readmit the air, and the piston is thus removed without a shock.

In order to form the vacuum properly, the liquid must be pumped in until it rises to the piston-rod; on depressing the piston there is no air left underneath it. The tube is now full of liquid, and by depressing the spring valve the liquid is run off, until it is as high as the lowest mark on the tube, when the temperature has been for two or three minutes at the lowest degree of the mercury thermometer.

Fig. 53.



Any salts or vegetable substances present in wines or alcoholic liquors do not materially affect the result. There is no occasion to fear the presence of any liquid more dilatable than alcohol, since such liquids are more expensive, and may, besides, be detected by their peculiar taste and smell, The same reasoning is also applicable to liquids less dilatable than water. The initial temperature, 25° C., was selected because water may always be found below that temperature in summer. The final degree, 50° C., was chosen to avoid the effect of evaporation, which might diminish the actual degree if it approached too near the boiling point; and the range between this and 25° C. was found sufficient. Besides, these two points offer great facilities for the experiment, as, if it be conducted in a vessel containing about a quart of water, a small spirit lamp underneath it will be sufficient to maintain either the one or the other. The plate carrying the thermometers serves to agitate the water, that its temperature may be uniform throughout.

DICAS' hydrometer is used in America for testing distilled liquors; it is made of copper, with a stem pointed on the summit to receive brass poises, and is accompanied by a graduated ivory scale, with a sliding rule and thermometer to make corrections for temperature. By this instrument the strength of the spirit is indicated, as with Sikes' hydrometer, by a certain number above or below proof; it is not much used in this country.

The alcoholometer of TRALLES is used in Russia, those of CARTIERS and GAY-LUSSAC in France, all of which determine the percentage by volume of alcohol in a liquid, and by means of the calculation which is given in the foregoing, the percentage by weight is obtained. Having the percentage of alcohol by weight in a liquid, the quantity of water is likewise found by deducting the amount of alcohol from 100; but if the amount of alcohol be determined by volume, this rule will not answer, since, on mixing alcohol and water, a contraction takes place. In the distillation of spirit it is often necessary to reduce stronger alcoholic liquors to lower degrees of strength; and unless the amount of contraction be known, considerable labour will be attendant on bringing the mixture to the desired quality. The following table shows the relative volumes of alcohol and water which, when mixed, make up 100:—

100 Volumes of spirit contain at 59° Fahr (15° C.).		100 Volumes of spirit contain at 59° Fahr. (15° C.).	
Volume of alcohol.	Volume of water	Volume of alcohol.	Volume of water.
100	0 00	45	58·64
95	6·18	40	63·44
90	11·94	35	68·14
85	17·47	30	72·72
80	22·87	25	77·24
75	28·19	20	81·72
70	33·14	15	86·20
65	38·615	10	90·72
60	43·73	5	95·31
55	48·77	0	100·00
50	53·745		

The annexed table by GAY-LUSSAC shows the volume of water per cent. which is to be added to a liquor, of whatever strength, to bring it to any degree of dilution.

In this table the top horizontal column indicates the percentage by volume of the spirit which is required to be produced. The vertical columns under the top line specify the number of volumes of water which are to be added to 1000 volumes of alcohol, the richness of which is pointed out in the vertical column at the left-hand side of the table, in order to obtain the spirit properly diluted.

GAY-LUSSAC'S TABLE FOR DILUTION OF ALCOHOL.

1000 vols. of alcohol of per cent. by vol.	Desired strength of the spirit.																			
	Per cent. by volume.																			
	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
31	33																			
32	67	32																		
33	100	65	31																	
34	134	97	63	30																
35	167	129	94	61	30															
36	201	162	126	91	59	29														
37	234	194	157	122	89	58	28													
38	268	227	189	153	119	86	56	27												
39	302	260	220	183	148	115	84	55	27											
40	335	292	252	214	178	144	112	82	53	26										
41	369	325	284	245	208	173	140	109	80	52	25									
42	403	358	315	275	238	202	169	137	107	78	51	25								
43	437	390	347	306	268	231	197	164	134	104	76	50	24							
44	471	423	379	337	298	261	225	192	160	130	102	75	49	24						
45	505	456	411	368	328	290	254	220	187	157	127	99	73	47	23					
46	539	489	443	399	358	319	282	247	214	183	153	124	97	71	46	23				
47	573	522	474	430	388	348	310	275	241	209	179	149	122	95	70	46	22			
48	607	555	506	461	418	377	339	303	268	235	204	174	146	119	93	68	45	22		
49	641	588	538	492	448	407	367	330	295	262	230	200	171	143	116	91	67	44	21	
50	675	621	570	523	478	436	396	358	322	288	256	225	195	167	140	114	89	66	43	21
51	709	654	602	554	508	465	424	386	349	314	281	250	220	191	163	137	112	87	64	42
52	743	687	634	585	539	495	453	414	376	341	307	275	244	215	187	160	134	110	86	63
53	777	720	666	616	569	524	482	442	403	367	333	300	269	239	210	183	157	132	107	84
54	811	753	699	647	599	553	510	469	431	394	359	325	293	263	234	206	179	153	129	105
55	846	786	731	679	629	583	539	497	458	420	385	350	318	287	257	229	202	176	151	127
56	880	820	763	700	660	613	568	525	485	447	411	376	343	311	281	252	224	198	172	148
57	914	853	795	741	690	642	596	553	512	473	436	401	367	335	305	275	247	220	194	169
58	949	886	827	772	721	672	625	581	540	500	462	426	392	359	328	298	269	242	216	190
59	983	919	860	804	751	701	654	609	567	527	488	452	417	384	352	321	292	264	237	212
60	1017	953	892	835	781	731	683	637	594	553	514	477	442	408	375	345	315	286	259	233
61	1052	986	924	867	812	760	711	665	622	580	540	503	467	432	399	368	338	309	281	254
62	1086	1019	957	898	842	790	740	694	649	607	566	528	491	456	423	391	360	331	303	276
63	1121	1053	989	929	873	820	769	722	676	633	593	554	516	481	447	414	383	353	325	297
64	1155	1086	1022	961	904	850	798	750	704	660	619	579	541	505	471	438	406	376	346	318
65	1190	1120	1054	992	934	879	827	778	731	687	645	605	566	529	494	461	429	398	368	340
66	1224	1153	1086	1024	965	909	856	806	759	714	671	630	591	554	518	484	451	420	390	361
67	1259	1187	1119	1055	995	939	885	834	786	741	697	656	616	578	542	508	474	443	412	383
68	1293	1220	1151	1087	1026	969	914	863	814	767	723	681	641	603	566	531	497	465	434	404
69	1328	1254	1184	1118	1056	998	943	891	841	794	750	707	666	627	590	554	520	487	456	426
70	1363	1287	1216	1150	1087	1028	972	919	869	821	776	732	691	652	614	578	543	510	478	447
71	1397	1321	1249	1182	1118	1058	1001	948	897	848	802	758	716	676	638	601	566	532	500	469
72	1432	1354	1282	1213	1149	1088	1030	977	924	875	828	784	741	701	662	625	589	555	522	491
73	1467	1388	1314	1245	1180	1118	1060	1005	952	902	855	810	767	725	686	648	612	578	544	512
74	1502	1422	1347	1277	1211	1148	1089	1033	980	929	881	835	792	750	710	672	635	600	567	534
75	1536	1456	1380	1309	1241	1178	1118	1061	1008	956	908	861	817	775	734	695	658	623	589	556
76	1571	1489	1413	1340	1272	1208	1147	1089	1035	983	934	887	842	799	758	719	681	645	611	578
77	1606	1523	1445	1372	1303	1238	1177	1118	1063	1011	961	913	867	824	782	743	705	668	633	599
78	1641	1557	1478	1404	1334	1268	1206	1147	1091	1038	987	939	893	849	807	766	728	691	655	621
79	1676	1591	1511	1436	1365	1299	1235	1175	1119	1065	1014	965	918	873	831	790	751	713	678	643
80	1711	1625	1544	1468	1396	1329	1265	1204	1147	1092	1040	991	943	898	855	813	774	736	700	665
81	1746	1658	1577	1500	1427	1359	1294	1233	1175	1119	1067	1017	969	923	879	837	797	759	722	687
82	1781	1692	1610	1532	1458	1389	1323	1261	1203	1147	1093	1043	994	948	904	861	821	782	745	709
83	1816	1726	1643	1564	1489	1419	1353	1290	1231	1174	1120	1069	1020	973	928	885	844	805	767	731
84	1851	1760	1676	1596	1521	1450	1382	1319	1259	1201	1147	1095	1045	998	952	909	867	828	789	753
85	1886	1794	1709	1628	1552	1480	1412	1348	1287	1229	1173	1121	1071	1023	977	933	891	851	812	775
86	1921	1828	1742	1660	1583	1510	1442	1376	1315	1256	1200	1147	1096	1048	1001	957	914	874	834	797
87	1956	1863	1775	1692	1614	1541	1471	1405	1343	1284	1227	1173	1122	1073	1026	981	938	897	857	819
88	1992	1897	1808	1724	1645	1571	1501	1434	1371	1311	1254	1200	1147	1098	1050	1005	961	920	880	841
89	2027	1931	1841	1757	1677	1602	1531	1463	1400	1339	1281	1226	1173	1123	1075	1029	985	943	902	863
90	2062	1966	1875	1789	1708	1633	1561	1492	1428	1367	1308	1252	1199	1148	1100	1053	1009	966	925	886

GAY-LUSSAC'S TABLE FOR DILUTION OF ALCOHOL.—*Continued.*

1000 vols. of alcohol of per cent. by vol.	Desired strength of the spirit.																								
	Per cent. by volume.																								
	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74
51	21																								
52	41	20																							
53	62	41	20																						
54	83	61	40	19																					
55	103	81	60	39	19																				
56	124	102	80	59	38	19																			
57	145	122	100	78	58	38	19																		
58	166	142	120	99	77	57	37	18																	
59	187	163	140	118	96	76	56	37	18																
60	208	183	160	137	116	95	74	55	36	18															
61	229	204	180	157	135	114	93	73	54	35	17														
62	250	225	200	177	155	133	112	92	72	53	35	17													
63	271	245	221	197	174	152	131	110	90	71	52	34	17												
64	292	266	241	217	194	171	150	128	109	89	70	52	34	17											
65	313	286	261	237	213	190	168	147	127	107	88	69	51	33	16										
66	334	307	281	256	233	209	187	166	145	125	105	86	68	50	33	16									
67	355	328	301	276	252	229	206	184	163	143	123	104	85	67	49	32	16								
68	376	348	322	296	272	248	225	203	181	160	140	121	102	84	66	49	32	16							
69	397	369	342	316	291	267	244	221	200	178	158	138	119	101	82	65	48	32	16						
70	418	390	362	336	311	286	263	240	218	196	176	156	136	117	99	81	64	47	31	15					
71	439	411	383	356	331	306	282	259	236	214	193	173	153	134	116	98	80	63	47	31	15				
72	460	431	403	376	350	325	301	277	255	232	211	191	171	151	132	114	97	79	63	46	30	15			
73	482	452	424	396	370	344	320	296	273	251	229	208	188	168	149	131	113	95	78	62	46	30	15		
74	503	473	444	416	390	364	339	315	291	269	247	226	205	185	166	147	129	111	94	77	61	45	30	15	
75	524	494	465	437	409	383	358	333	310	287	265	243	222	202	183	164	145	127	110	93	76	60	45	29	14
76	546	515	485	457	429	403	377	352	328	305	283	261	240	219	199	180	162	143	126	109	92	75	60	44	29
77	567	536	506	477	449	422	396	371	347	323	300	278	257	236	216	197	178	159	142	124	107	91	75	59	44
78	588	557	527	497	469	442	415	390	365	341	318	296	274	253	233	213	194	176	157	140	123	106	90	74	58
79	610	578	547	517	489	461	434	409	384	360	336	314	292	271	250	230	211	192	173	155	138	121	105	88	73
80	631	599	568	538	509	481	454	428	402	378	354	331	309	288	267	247	227	208	189	171	153	136	120	103	87
81	653	620	588	558	529	500	473	447	421	396	372	349	327	305	284	263	243	224	205	187	169	152	135	118	102
82	674	641	609	578	549	520	492	465	440	415	390	367	344	322	301	280	260	240	221	203	184	167	150	133	117
83	696	662	630	599	569	540	512	485	458	433	409	385	362	339	318	297	276	256	237	218	200	182	165	148	131
84	717	683	651	619	589	559	531	504	477	451	427	403	379	357	335	313	293	273	253	234	216	198	180	163	146
85	739	705	671	640	609	579	550	523	496	470	445	421	397	374	352	330	309	289	269	250	231	213	195	178	161
86	761	726	692	660	629	599	570	542	515	488	463	438	415	391	369	347	326	305	285	266	247	229	211	193	176
87	782	747	713	681	649	619	589	561	534	507	481	456	432	409	386	364	343	322	302	282	263	244	226	208	191
88	804	769	734	701	669	639	609	580	553	526	500	474	450	426	403	381	359	338	318	298	279	260	241	223	206
89	826	790	755	722	690	659	629	600	572	544	518	493	468	444	421	398	376	355	334	314	295	275	257	239	221
90	848	812	777	743	710	679	648	619	591	563	537	511	486	462	438	415	393	372	351	331	311	291	273	254	236

GAY-LUSSAC'S DILUTION TABLE.—*Concluded.*

1000 vols. of alcohol of per cent. by vol.	Desired strength of the spirit.														
	Per cent. by volume.														
	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89
76	14														
77	29	14													
78	43	28	14												
79	57	43	28	14											
80	72	57	42	28	14										
81	86	71	56	42	27	14									
82	101	85	70	56	41	27	13								
83	116	100	85	70	55	41	27	13							
84	130	114	99	84	69	55	40	27	13						
85	145	129	113	98	83	68	54	40	26	13					
86	159	143	127	112	97	82	68	54	40	26	13				
87	174	158	142	126	111	96	81	67	53	39	26	13			
88	189	172	156	140	125	110	95	81	66	53	39	26	13		
89	204	187	171	155	139	124	109	94	80	66	52	39	26	13	
90	219	202	185	169	153	138	123	108	94	79	66	52	39	26	13

As an example. If it be required to prepare an alcohol of 50 per cent. from a liquor which is 80 per cent., the number, 50, is sought in the top horizontal line of strengths, and in the vertical line under this figure the number 631 is found in a horizontal line with 80 in the left-hand vertical column; this figure indicates the number of volumes of water which are to be added to 1000 volumes of alcohol of 80 per cent. to bring it to the required degree of dilution.

Again, if it be requisite to bring a spirit of 60 per cent. to 30 per cent., the latter figure is found in the horizontal column at the top, and in the vertical column under it, in a line with 60 on the left hand, 1017 is seen, which is the number of measures of water required to reduce 1000 volumes of the strong liquor to the strength of 30 per cent.

The tables for determining the percentage of alcohol, as given in the preceding pages, serve to give a clear view of the composition of alcoholic liquors of different states of dilution, and under the influence of various degrees of temperature and pressure, enabling the diligent student to draw up tables of great accuracy and of less extent for reference on all ordinary occasions. From what has been said upon the properties of alcohol, in relation to its real specific gravity, it will be observed that none of the enumerated tables are strictly correct, since the density of absolute alcohol—to which all the other densities bear a proportionate analogy—stated in them, is considerably higher than that assigned to it by chemists.

The annexed is a contraction of the foregoing table of GAY-LUSSAC, showing the dilution per cent. in reducing liquors to a lower strength. The upper horizontal column contains the per cent. of the stronger alcohol, and the vertical columns below, the bulk of water which is to be added to 100 volumes of it, to produce spirit of the quality indicated in the left-hand column.

Desired strength in per cent.	100 vols. of alcohol of per cent. by vol.								
	90	85	80	75	70	65	60	55	50
85	6·56								
80	13·79	6·83							
75	21·89	14·48	7·20						
70	31·05	23·14	15·35	7·64					
65	41·53	33·03	24·66	16·37	8·15				
60	53·65	44·48	35·44	26·47	17·58	8·76			
55	67·87	57·90	48·07	38·32	28·63	19·02	9·47		
50	84·71	73·00	63·04	52·43	41·73	31·25	20·47	10·35	
45	105·34	93·30	81·38	69·54	57·78	46·09	34·46	22·90	11·41
40	130·80	117·34	104·01	90·76	77·58	64·48	51·43	38·46	25·55
35	163·28	148·01	132·88	117·82	102·84	87·93	73·08	58·31	43·59
30	206·22	188·57	171·05	153·61	136·04	118·94	101·71	84·54	67·45
25	266·12	245·15	224·30	203·53	182·83	162·21	141·65	121·16	100·73
20	355·80	329·34	304·01	278·26	252·58	226·98	201·43	175·96	150·55
15	505·27	471·00	436·85	402·81	368·83	334·91	301·07	267·29	233·64
10	804·54	753·55	702·89	652·21	601·60	551·06	500·59	450·19	399·85

Adulterations of Spirituous Liquors and their Detection.—The sophistication of alcoholic liquors has been practised to give to many solutions containing very little spirit, the appearance and some of the physical properties which would be conferred by alcohol; and adulterations have also been practised with a view, as it were, of veiling the quantity of spirit.

The counterfeiting of strong alcoholic liquors apparently as weaker spirit, or passing them off as quite a different liquid, was fostered in the wine-growing countries of the Continent, where large quantities of brandy were manufactured; and before the proper means of detection were at command the strongest brandy was often sold to the merchants disguised as ordinary wine, or a much weaker spirit, and by this means the *Octroi* duties were eluded. The imposition had long been practised after the introduction of various hydrometric or alcoholometric scales for the determination of the amount of alcohol in spirituous liquors; for as most of these were on the principle of the gravity test, various substances were added which would heighten the density, and make it appear that the spirit was much more aqueous than it really was. In other instances the spirit was passed upon the excise as quite a different article, sometimes as a deodorising agent, while at other times it was made to assume the character of wood naphtha. Expedients such as these have been practised in this country; and in large towns where much alcoholic liquor is consumed, drinks are frequently sold to the public which are said to be alcoholic, but in reality contain little or no spirit. To defraud the excise, sugar or other extractive matter is added to the spirit to increase the specific gravity, and sometimes wood-spirit, turpentine, pyroligneous acid, chlorine water, or other bodies possessing a strong odour, are added to the liquor, and in this case it is represented as not being alcoholic.

The detection of these frauds is, for the most part, easy and expeditious. When sugar, extractive matter, pyroligneous acid, turpentine, &c., are suspected, it is only necessary to distil a portion of the liquid, and determine the density of the distillate by the hydrometer, or specific gravity bottle, and on referring to the corresponding gravity in either of the tables already given, under *alcoholometry*, the corresponding value of alcohol is found. When a liquor is disguised as wood naphtha, it is more difficult to determine the amount of alcohol; distillation is in this case ineffectual, since the naphtha passes over at even a lower temperature than the alcohol. The following is the method recommended by URE for the detection of alcohol in wood or coal naphtha, or pyroligneous acid:—

A small quantity of nitric acid of specific gravity 1·45 is first to be added to the spirit under examination, and if alcohol be present it will immediately produce an effervescence of nitrous ether (ethyl nitrite, C_2H_5,NO_2), which may be recognized as such by its odour. The mixture is then treated with a solution of mercury in nitric acid—which is prepared by dissolving 100 grains of mercury in 1 fluid ounce of acid, with the help of heat. Soon after this addition, and especially on raising the temperature, the mixture begins to effervesce and to evolve thick ethereal vapours; should the effervescence become too violent, it must be quelled by immediately withdrawing the fire, and cooling the vessel. A yellowish grey precipitate falls down, which is mercuric fulminate ($HgC_2N_2O_2$), and which should be immediately separated by decanting or filtering the liquor from it, washing the precipitate on the filter with a little distilled water, and carefully drying it at a heat which must not exceed 100° Fahr. (37°·7 C.); after which it is weighed. The quantity of mercuric fulminate obtained is nearly equal to that of the alcohol contained in the wood-spirit; and at any rate, the formation of the detonating salt is quite characteristic of the presence of alcohol, since wood-spirit treated by nitric acid in the presence of mercury or silver produces neither fulminate of silver nor fulminate of mercury.

In applying this test the greatest care should be exercised, and every precaution taken to prevent contact of any hard body with the precipitate, since the fulminates of silver and mercury, and especially the former, are very explosive; silver fulminate ($Ag_2C_2N_2O_2$) has been known to explode by contact with a glass rod, even under water; the mercuric fulminate is less explosive, and is on that account preferred. For the purpose of collecting these compounds, the feather of a quill should be used; and if the quantity exceeds a few grains, it should be collected in several filters so as to handle only small portions at a time. During the evolution of the ethereal vapours all approach of flame should be carefully avoided.

The same chemist gives the following as the principal tests whereby to discern alcohol from wood naphtha, and also whether the latter is genuine or mixed with alcohol:—

1st. The boiling point of pure wood naphtha spirit is at least 20° Fahr. (5°·5 C.) below that of alcohol of the same density, and it exhales the characteristic, pungent, and offensive odour of aldehyde. In the course of his experiments he found the boiling point of—

	Fahr.	C.
Wood-spirit, of specific gravity ·870, to be	144°	62°·2
Alcohol, of like gravity,.................	180°	82°·2
Wood-spirit, of specific gravity ·832,.....	140°	60°·0
Alcohol, of the same density,............	171°·1	77°·2

If 10 per cent. of naphtha be mixed with alcohol, the boiling point is lowered at least 6° Fahr. (3°·3 C.)

2nd. When rectified naphtha is distilled at the temperature of boiling water from a large quantity of lime, the distillate is unchanged in its gravity, whilst if alcohol, or a mixture of alcohol and naphtha, be subjected to the same treatment, the first portions that come over are nearly absolute, and stand at a density below ·800, and contain, at 60° Fahr. (15°·5 C.), about 70 per cent. over proof. The reason of this characteristic difference seems to be that naphtha possesses a stronger affinity for water than alcohol.

3rd. When water is added to alcohol, the specific gravity of the liquor becomes reduced in a less proportion than when wood-spirit of the same gravity as the alcohol is diluted with the same quantity of water. Thus, for example, if alcohol of a given density is diluted with a certain quantity of water, so as to bring it to specific gravity 0·920, wood-spirit of the same original gravity, and diluted with the same quantity of water, will become of specific gravity 0·926 or 0·927.

When brandies, gins, and other alcoholic liquors are artificially made by admixture of various ingredients with alcohol, as is directed under these heads, it is not uncommon to find that the alcohol, in such compounded articles, is attenuated as low as possible, and that the agreeableness of taste and the pungency of flavour peculiar to the genuine beverages, are conferred upon the mixture by means of pepper, cayenne, or other acrid substances. These sophistications are discovered by evaporating a known quantity of the liquid to dryness at a gentle heat, when the added substances will be found as a residue.

Acetates of copper and lead are rarely found in brandies, owing to the repeated distillations to which the spirit is subjected, but when the old stills are employed, the solder connecting the seams of the still is apt to be dissolved by the small quantity of acetic acid present in the liquors; plumbic acetate (sugar of lead) has likewise been known to be added to facilitate the clarifying process. Liquors thus treated are extremely pernicious, since the acetates of lead are highly poisonous. By filtering the brandy through animal charcoal, and adding sulphuric acid to the clear liquor, if the lead is present in excess a white precipitate appears; if there is no precipitate, a stream of sulphuretted hydrogen is to be transmitted through the liquid, and if any lead is present, a black precipitate or coloration is produced. Should a white precipitate be obtained by the action of sulphuric acid or sodium sulphate on the brandy, it is turned black by the addition of ammonium sulphide; and if the precipitate should be bulky it may be mixed with a little sodium carbonate, and reduced on charcoal before the blowpipe to a globule of metal.

Copper may be detected by filtering a portion of the brandy through animal charcoal, to decolorize it; ammonia is then added to the clear liquor, to which it will impart a blue tinge, if copper be present in sufficient quantity. Several hours are sometimes requisite to determine this appearance. The presence of copper may also be detected by immersing a blade of perfectly clean iron in the brandy, and leaving it there for a few hours, when it will be found coated with a film of metallic copper. The brandy, first decolorized by animal charcoal, may also be tested for copper by a solution of potassium ferrocyanide, which will produce a reddish brown precipitate with this metal.

ALUM.—*Alun*, French; *alaun*, German; *alumen*, Latin. According to BECKMAN alum was first discovered in Asia, and was certainly not known to the Greeks or Romans, what the latter called *alumen* being green vitriol (ferrous sulphate). The Greeks and Romans mention only natural alum; now alum is very rarely produced spontaneously, and then only as an efflorescence on stones in the neighbourhood of certain mineral waters. Crystals of alum are also occasionally found upon minerals containing much aluminium when they have been long exposed to the weather; but even then they are so small and so much scattered as to require close observation to discover them. The celebrity acquired by *alumen* among the ancients, as a substance extremely useful in dyeing and medicine, was entirely forgotten at the time that modern alum came into use; but it was again revived when it was discovered that alum could be manufactured from aluminous minerals containing sulphur compounds. This circumstance has served in some measure to strengthen the opinion that the alum of the ancients and of the moderns is synonymous, although the former was found and the latter was extracted by a chemical process. Some historians of the fifteenth century speak of the alum works as if the manufacture in Europe was only a revival.

Alum owes the high estimation in which it is held to its value as a mordant in dyeing.

Alum works existed many centuries ago at Roha, or Roccha, in Mesopotamia, whence the old name of Roch alum is applied to this salt. This is the opinion of Leibnitz, who states that *alumen roccæ* was that kind first procured from Rocca, and that the name was subsequently given to every good species of alum. A few are of opinion that alum obtained from alum-stone has been so called to distinguish it from the alum from schists (schist was employed for making alum in the time of Agricola), which usually contains more iron than the former; and others assert that alum acquired the name *rocca* from the aluminous rocks of Tolfa.

At a later date alum was manufactured near Smyrna, and in the fifteenth century there were alum factories in the vicinity of Constantinople, where John di Castro learned his art, as will be hereafter noticed.

The inhabitants of Genoa, and other commercial people of Italy, imported alum from the above places into Western Europe for the use of dyers of red cloth. When these countries were taken by the Turks the Italians sought for and discovered aluminous minerals in their own soil, which caused the abandonment of many of the Turkish alum works.

Ducas describes very minutely the alum works at Foya Nova, near Smyrna. Francis and Griffith state that in Phocis, lying close to Ionia, there is a mountain rich in aluminous mineral. The stones found at the summit are first calcined in the fire, and then reduced to powder by throwing them into water. The moist mass is put into a kettle, a little more water added, and the whole having been made to boil, the powder is lixiviated, the thick part which falls to the bottom in a cake is preserved, and the hard and earthy portions are discarded. The cake is afterwards allowed to dissolve in vessels for four days, at the end of which the alum is found in crystals around their edges, and their bottoms are also covered with the salt; the remaining liquor is poured into a kettle, diluted with water, and more powder added, then boiled as before, and put into proper vessels to crystallize. The alum obtained in this manner is preserved as an article very necessary for dyers. Captains of ships bound from the Levant to Europe consider alum as a very convenient and useful cargo for their vessels.

The alum works near Civita Vecchia are, by Italian historians, asserted to have been the first in Europe; they are the oldest carried on at present. They were founded by John di Castro, who learned the process near Constantinople. He was there trading in Italian cloths and dyestuffs at the time the superb city fell into the hands of the Turks; after this he returned to his own country, and having found, in the neighbourhood of Tolfa, a plant which he had observed growing abundantly in the aluminous districts of Asia, he conjectured that the virgin soil might also contain the same salt, and the astringency of its taste proved he was correct. On this discovery factories were immediately erected, the produce of which was sold to the Venetians, the Florentines, and the Genoese. The stones were first calcined, a large quantity of water was then thrown over them, and when they were entirely dissolved the lie was boiled in great leaden caldrons; after which it was run into wooden vats and allowed to evaporate spontaneously, the result being exceedingly good alum. Pope Pius II. employed more than 800 persons in preparing it. The plant which first induced Castro to search for alum was the prickly evergreen, *Ilex aquifolium*, which in Italy is still considered as an indication that the regions where it thrives abound with alum. This shrub is, however, frequently found growing where there is not the slightest trace of this salt.

It appears, from all that can be learned, that the art of boiling alum was first understood in Italy, but not previous to 1548. The great revenue which the Apostolic Chamber derived from alum induced many to seek aluminous minerals, and factories were built wherever such were found. Alum works soon appeared in Germany; and in 1554 at Oberkaufungen, in Hesse, a factory was in full operation. In 1566 letters patent were granted in England to Cornelius de Vos, a Dutchman, for making "allom and copperas." A bill passed the House of Commons confirming this grant, which it appeared De Vos had assigned to Lord Mountjoye. Nothing is known of his or Lord Mountjoye's subsequent proceedings. Shortly after this date, however, an alum factory was erected at Gisborough, in Yorkshire, in the reign of Queen Elizabeth, by Sir Thomas Chaloner, who, observing the trees tinged with an unusual colour, made him suspicious of its being owing to some mineral in the neighbourhood. He ascertained that the strata abounded with an aluminous salt. At that time the English being strangers to the methods of managing it, there is a tradition that Sir Thomas was obliged to seduce some workmen from the Pope's alum works, then the greatest in Europe.

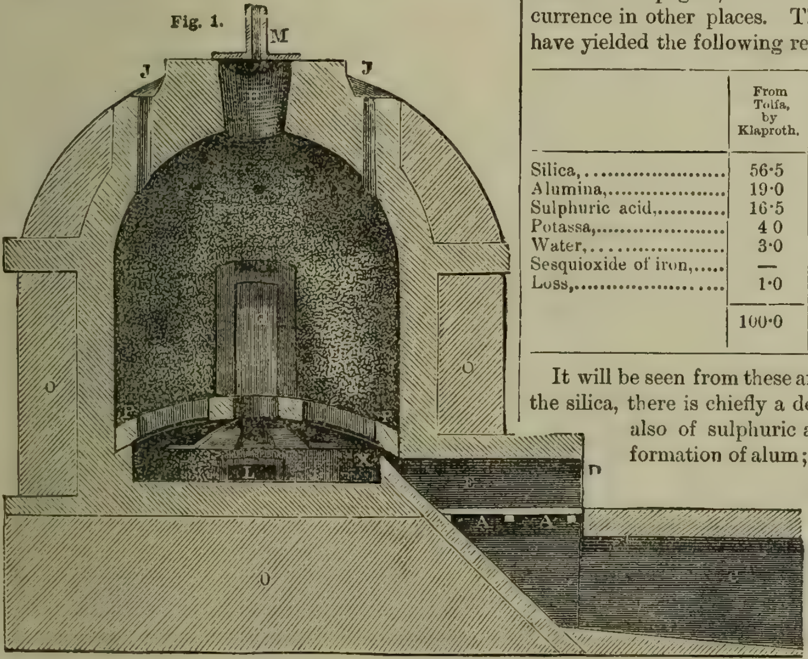
Before entering minutely into the fabrication of alum, it will be proper to state how and where the salt is obtained. The greater portion of the alum in this country is manufactured from alum shale, a bituminous slaty clay containing iron bisulphide diffused in very fine particles throughout its mass; it has a bluish or greenish-black colour, and eliminates sulphurous acid when burned, acquiring thereby an aluminous taste. Many of the alum slates crumble to pieces, or suffer disintegration, on exposure to the air; their sulphur becomes gradually converted into sulphuric acid by absorbing oxygen from the atmosphere, while, simultaneously, the iron is oxidized, and ferrous sulphate and aluminium sulphate are produced. These are separated from the rest of the mass by lixiviation with water. The solution is then concentrated and potassium chloride added. The iron and potassium salts are transformed into ferrous chloride and potassium sulphate, and the latter combining with the aluminium sulphate, constitutes the alum of commerce.

Alum may be prepared by decomposing clay with sulphuric acid. The decomposition is effected by calcining pure clay, grinding the mass to powder, and mixing it with about a half per cent. of sulphuric acid. This mixture is then to be heated in a furnace till the mass becomes very thick; afterwards left to repose for a month or more, and then lixiviated with water to wash out the aluminium sulphate. The addition of potassium sulphate converts it into alum.

MANUFACTURE OF ALUM.—Two alums only are applied in the arts; these are composed of aluminium sulphate, $Al_2(SO_4)_3$, in combination with potassium sulphate or ammonium sulphate, thus:—Potassio-aluminic sulphate, $AlK(SO_4)_2 12H_2O$; ammonio-aluminic sulphate, $Al(NH_4),(SO_4)_2 12HO$.

The first of these, potash alum, is by practical men simply called alum, whilst the second variety is distinguished by the name of *ammonia alum.* The latter is easily distinguished from the former by its giving off ammonia when triturated with quicklime. Potash alum is preferred by turkey-red dyers; but both are used by dyers and calico-printers solely for their alumina, and in this particular they are accounted nearly of equal value; the other constituents being almost useless.

Fig. 1.



The property which alum possesses, of separating from its concentrated solutions in large, well-defined crystals; the purity of the alumina in this salt, and which is necessary in the applications of alum, enables the purchaser to pay for the sulphuric acid, water, and alkali, although they are useless except for effecting the crystallization. Aluminium sulphate is only with great difficulty separated from the many other extraneous salts (particularly ferrous sulphate) that accompany it in the manufacture; whilst alum, from the ease with which it dissolves in hot water, and its sparing solubility in cold, is readily separable from any adventitious substances.

PRODUCTION OF ALUM FROM ALUM STONE.—Alum is obtained in much larger quantity from alum rock, a formation of volcanic origin, than from any other source. This is a massive, granular, only partially crystalline, transparent, and not homogeneous rock, which frequently incloses quartz, sometimes iron pyrites and manganese ore. Its colour is yellowish, passing into green, grey, red, or brown. The pure mineral alum stone, *alunite*, sometimes occurs in it in distinct crystals, which have been found to consist of a basic aluminium sulphate, with potassium sulphate, and is, therefore, a basic alum, or, more probably, a combination of neutral potassio-aluminic sulphate, with aluminium hydrate, $AlK(SO_4)_2Al_2O_3,H_2O$.—*Rammelsberg.* It differs, therefore, from alum in containing an excess of alumina. Alum rock is a massive alunite, but of a less pure character; it is found at Tolfa, near Civita Vecchia; at Montione, in the Comitats, Beregh, and Zemplin, in Hungary; at Mont d'Or, in France; and in the Greek islands, Milo and Nipoglio; but is not of very common occurrence in other places. The analyses of this rock have yielded the following results:—

	From Tolfa, by Klaproth.	From Beregszaz, by Klaproth.	From Montione, by Descotil.	From Mont d'Or, by Cordier
Silica,	56·5	62·3	—	28·4
Alumina,	19·0	17·5	40·0	31·8
Sulphuric acid,	16·5	12·5	35·6	27·0
Potassa,	4 0	1·0	13·8	5·8
Water,	3·0	5·0	10·0	3·7
Sesquioxide of iron,	—	—	—	1·4
Loss,	1·0	1·7	0·6	1·9
	100·0	100·0	100·0	100 0

It will be seen from these analyses that, overlooking the silica, there is chiefly a deficiency of potassa, and also of sulphuric acid, in the rock, for the formation of alum; but in the mineral from Tolfa, for instance, there is about 3 per cent. of sulphuric acid and 14 per cent. of alumina more than are requisite to form alum with the 4 per cent. of potassa. The alum stone from Beregszaz also contains an excess of 9 per cent. of acid and 16 per cent. of earth; that from d'Or 6 per cent. of acid and 25 per cent. of alumina. At Tolfa, where the alum stone comes to the surface, a quantity of alum is produced proportionate to the amount of potassa in the rock, and the remainder, particularly the excess of alumina, is separated. This is effected by burning the stones in heaps, or furnaces similar to those used in preparing gypsum—Fig. 1—particular care being taken that the temperature does not rise too high.

The inner chamber of this kiln is divided into two unequal portions by an arch, P P, situated about a foot from the bottom. The upper part, into which the alum rock is introduced, partly through the door, G, and partly through the mouth, H, is provided with eight draught holes, J J, the ninth hole being formed by the tube in the covering plate, M. The lower chamber, or fire-space, is in connection with the fire, E, which is situated in front of the kiln, and which is replenished with fuel through the door, D. The draught-channel, C, terminates in the ash-pit under the grate, A, on which the fire is made. The flame enters at X, below the perforated arch, P, where it is uniformly disseminated over the whole area of the kiln, and passes through the fissures, *e e*, and the mass of materials, in an upward direction, escaping at the apertures, J J. If the heat is not uniform throughout the kiln, the draught-holes, J J, are opened on that side where it is least intense, and where it is desirable to lead the flame, while those on the other side are closed. The aperture, L, is used for clearing the fire-chamber, and is closed, as well as G and H, during the firing. Particular attention is given to the maintenance of a proper temperature. O O represents the exterior walls of the kiln, made of non-conducting materials to secure the retention of the heat.

At a red heat aluminium sulphate is decomposed, yielding partly anhydrous sulphuric acid, and partly oxygen and sulphurous acid. As soon as these vapours appear the burning is stopped, and the mass is transferred to walled cisterns, where it is repeatedly moistened with water, and is allowed to disintegrate for three or four months, at the expiration of which period it is converted into a soft mud, tasting perceptibly of alum, which may then be dissolved out with water. If the alum stone contained an excess of aluminium hydrate this would infallibly react upon the alum, and form with it an insoluble compound containing basic sulphate—the burning expels the water from the hydrate of alumina, and thus renders it chemically inactive; the excess of alumina is thus separated from the compound, which then yields an alum soluble in water. During the evaporation—until the spec. grav. is 1·114 at 113° Fahr. (45° C.)—the lie still holds a fine ferruginous rose-red powder in suspension, which feebly colours the crystals, but is left behind when these are redissolved. The crystals contain potassa, but no ammonia, and are known in commerce under the name of *Roman alum.*

PRODUCTION FROM ALUM ORE.—The production of alum from alum shale and alum earth is systematically carried out or divided into three distinct operations: the production of aluminium sulphate; the addition of sulphate or chloride of the alkali to the concentrated cold solution of the former; and lastly, the purification of the alum by recrystallization.

Alum shale is a kind of clay slate impregnated with sulphide of iron and bituminous matters—allied to real clay slate by its firmness, appearance, slaty structure, and great extent. Although it is not so abundantly disseminated as many other species of rocks and minerals, it forms, nevertheless, beds of considerable extent in many localities, particularly in the Scandinavian peninsula; in Bohemia; in the Hartz, in Upper Bavaria; in Voigtland, in the mountainous districts of the Lower Rhine; in England, near Whitby; in Scotland, at Hurlet and Campsie, near Glasgow; in the Uralian Mountains. It may be also met with in many other districts, but not in sufficient quantity to be available for practical purposes.

The following analyses show the composition of the rocks:—

ALUM SHALE FROM SIEHDA, BY LAMPADIU.

Aluminium sulphate,	2.68
Potash alum,	0·47
Ferrous sulphate,	0·95
Sulphate of lime,	1·70
Silica,	10·32
Alumina,	9·21
Magnesia,	traces
Sesquioxide of iron,	2·30
Oxide of manganese,	0·31
Sulphur,	7·13
Water,	33·90
Carbon, &c.,	31·03
	100 00

ALUM SHALES, BY G. KERSTEN.

	Hermannsschachte.	Gluckaufgang.	Blucherschachte.
Carbonaceous matters,	41·10	27·92	34·20
Silica,	44·02	51·32	50·21
Sesquioxide of iron,	6·23	8·40	0·42
Alumina,	5·60	7·62	5·21
Magnesia,	0·32	0·26	0·53
Oxide of manganese,	0·12	traces	traces
Sulphur,	1·25	2·89	1·72
Sulphate of lime,	traces	traces	traces
Loss,	1·36	1·59	7·71
	100·00	100·00	100·00

ALUM SHALES, BY ERDMANN.

Soluble in acid.	Garnsdorff.		Wezelstein.	
Iron bisulphide,	7·533		10·166	
Silica,	0·060		0·100	
Sesquioxide of iron,	0·966		2·466	
Alumina,	1·833		3·166	
Lime,	0·400		1·000	
Magnesia,	trace		1·022	
		10·792		17·920
Insoluble in acid.				
Silica	50·066		52 200	
Alumina,	8·900		17·900	
Sesquioxide of iron,	1·300		3·366	
Magnesia,	1·000		1·133	
Lime,	trace		trace	
Coal,	22·833		0·803	
		84·099		75·402
Loss,		5·109		6·678
		100·000		100·000

Subjoined is the composition of several shales which are sometimes used in the manufacture of alum:—

	Locality unknown. D'Aubisson.	Dunmeniss, Devonshire. Stokes.	Gaggenan, Baden. Holtzmann.	Niedesselten, Nassau. Wimph.	Goslar, Hartz. Frick.	Breundaff, N. Coblentz. Frick.	Lehsten, Thuringerwald. Frick.	Prague. Plerschl.
Silica,	48·6	59·4	64·34	79·17	60·03	62·83	64·57	67·50
Alumina,	23·5	17·4	23·90	10·42	14·91	17·11	17·30	15·89
Sesquioxide of iron,	11·3	11·6	9·70	6·27	8·94	8·23	7·46	5·85
Oxide of manganese,	0·5	—	—	—	—	—	—	0·08
Lime,	—	2·1	—	—	2·08	0·83	1·16	2·24
Magnesia,	1·6	2·2	—	—	4·22	1·90	2·60	3·67
Potash,	4·7	—	—	—	3·87	4·17	1·99	1·23
Soda,	—	—	—	—	—	—	—	2·11
Strontia,	—	—	—	—	—	—	—	0·30
Oxide of copper,	—	—	—	—	0·28	0·27	0·30	—
Fluoride of calcium,	—	—	—	—	—	—	—	1·13
Phosphoric acid,	—	—	—	—	—	—	—	
Sulphur,	0·1	—	—	—	—	—	—	—
Carbon,	0·3	—	—	—	—	—	—	—
Carbonic acid,	—	—	—	—	5·67	4·66	4·62	—
Water,	7·6	6·4	2·22	2·78				—
Loss,	1·8	0·9	—	1·36	—	—	—	—
	100·0	100·0	100·16	100·00	100·00	100·00	100·00	100·00

The annexed is the composition of some shales from Whitby, in Yorkshire, and Campsie, near Glasgow:—

	Whitby Richardson. Top rock.	Whitby Richardson. Bottom rock.		Campsie. Top rock.	Campsie. Top rock.	Campsie. Bottom rock.
Iron bisulphide,	4·20	8·50	Sulphur,	22·36	23·44	Pyrites, 9·63
			Iron,	18·16	15·04	
Silica,	52·25	51·16		15·40	15·40	0·47
Protoxide of iron,	8·49	6·11		—	—	2·18
Alumina,	18·75	18·30		11·35	11·64	18·91
Lime,	1·25	2·15		1·40	2·22	0·40
Magnesia,	0·91	0·90		0·50	·32	2·17
Oxide of manganese,	traces	traces		0·15	—	0·55
Sulphuric acid,	1·37	2·50		—	—	0·05
Potassa,	0·13	traces		0·90	—	1·26
Soda,	0·20	traces		—	—	0·21
Chlorine,	traces	traces		—	—	—
Coal,	4·97	8·29	Carbon and Loss,	29·78	Carbon, 28·80	8·51
Water,	2·68	2·00		—	—	8·54
Loss,	4·80	8·09		—	3·13	0·59
	100·00	100·00		100·00	99·99	100·00

The Campsie alum ores, especially the upper, contain a large excess of pyrites, yielding of course more sulphuric acid than the alumina can take up, while the lower have a considerable excess of alumina; it is, therefore, the object of the manufacturers of alum to mix these ores in such a manner that the different ingredients may be made available as far as possible.

The composition of the residue from the Campsie ores, after calcination and washing out the alum, is:—

Silica,	38·40
Alumina,	12·70
Sesquioxide of iron,	20·80
Oxide of manganese,	traces
Lime,	2·07
Magnesia,	2·00
Potassa,	1·00
Sulphuric acid,	10·76
Water,	12·27
	100·00

It is well known that alum earth belongs to the more recent deposits occurring below the first strata of the tertiary coal formation, which are of a later period than the chalk. It is a massive but soft pulverizable mass, stratified, but not slaty, and of a dark-brown colour; it occupies basins of variable dimensions, according to the position of the neighbouring rocks. Very large deposits of this formation occur in the valley of the Oder, and are worked at Freienwalde and Muskau. It is no uncommon phenomenon, in the coal formations, for the clay and coal strata to permeate each other in those localities where they meet. These deposits, which frequently cover the coal formation, and are at other parts in alternate layers with the coal, play the part of alum ores, and may be worked for the production of alum when they contain a sufficient quantity of sulphide of iron, which is often the case. To this class belong the Scotch ores. In Upper Silesia it is even found profitable to make the refuse coal, or *brees*, which cannot well be used as fuel, subordinate to the production of alum; these coals leave an aluminous ash, and those which are rich in iron pyrites are only distinguished from a real alum ore by their large excess of combustible matter, and which in this case cannot be turned to account.

Iron pyrites, or the bisulphide of iron, is quite as indispensable to the production of alum as alumina itself. It is disseminated through the alum ores, partly in the well-known brilliant yellow crystals, or crystalline deposits, but chiefly in a very fine state of division, as a dull black powder, somewhat resembling the mass obtained by precipitating a salt of iron by ammonium sulphide. Hence, inasmuch as it was not perceptible to the eye, its presence has not only been overlooked in the following analyses, but actually denied:—

	Alum earth.	
	From Freienwalde. Klaproth.	From Putzberg. Bergmann.
Alumina,	16·00	10·90
Silica,	40·00	45·40
Magnesia,	0·25	—
Sulphur,	2·85	3·94
Carbon,	19·45	5·95
Protoxide of iron,	6·40	5·50
" manganese,	—	0·60
Protosulphate of iron,	1·80	5·73
Sulphate of alumina,	—	1·20
" lime,	1·50	1·71
" potassa,	0·50	1·75
Chloride of potassium,	0·50	0·35
Sulphuric acid,	—	0·47
Water,	10·75	16·60
	100·00	100·00

The sulphur is in combination with the iron, and not, as was formerly supposed, in the free state, or as sulphide of carbon. Although the constituents of alum earth are nearly the same in specimens taken from other localities, the proportions are nevertheless variable, as might have been expected from the mode in which the deposits are formed; so great, indeed, is the difference in this respect, that the examples given above can hardly be viewed as a fair average of these compounds. Pyrites and alum ores owe their property of being rapidly decomposed under the influence of atmospheric air to the fine state of division of the bisulphide, and probably, also, to the occasional presence of the protosulphide of iron. Massive crystalline pyrites is under the same circumstances but very slowly decomposed.

The combined action of air and moisture are essential to effect this change. The decomposition is occasioned by 7 equivalents of oxygen and 8 equivalents of water being taken up by the pyrites, FeS_2, which convert it into ferrous sulphate and sulphuric acid, thus:—

$$FeS_2 + 7O + 8H_2O = FeSO_4.7H_2O + H_2SO_4.$$

The combination of the oxygen with the iron and sulphur is accompanied by a spontaneous rise of temperature which results from the chemical union; as the process proceeds, the iron sulphide is converted as by roasting into monosulphide and sulphur, which immediately burn, the former being resolved into ferrous sulphate as shown above, and the latter into sulphurous acid, which is absorbed by the alumina. The aluminium sulphite thus formed is then by further absorption of atmospheric oxygen, transformed into aluminium sulphate ($Al_2(SO_4)_3$). The alum ore, when first taken from the ridges—calcined heaps—and covered with water (which is removed after a short interval), will be found to have yielded little sulphate of alumina to the solution, but a great deal of sesquisulphate of iron; while, after being allowed to remain for some time over the ore, the solution will be found to contain much sulphate of alumina and protosulphate of iron; alum-makers know that the first washes are not those which afford the most alum, unless the ore has been permitted to remain in the steeps for a length of time; they are also aware that more alum is procured by adding to the lie a portion of *mothers*, which are very rich in sesquisulphate of iron, than is obtained by pure water, *per se*.

The sulphides of iron are, therefore, only necessary to the production of alum as affording sulphuric acid to unite with the alumina. Besides the acid produced by the second portion of sulphur, an additional quantity of sulphuric acid is furnished to the alumina by the decomposition of the green vitriol, the ferrous oxide being speedily converted into ferric oxide (Fe_2O_3) by the oxygen of the air, and precipitated in the form of a basic salt. Potassa, which is never altogether wanting in the alum ores, sets free in a similar manner sulphuric acid by the production of potassio-ferric sulphate (iron alum, $FeK(SO_4)_2 12H_2O$). Ferric sulphate is also decomposed by aluminium hydrate, forming aluminium sulphate; this reaction is, however, very slow, and practically of small account.

Potash-iron alum is also always formed when potassium sulphate and ferric sulphate are together in acid solution, and by spontaneous evaporation crystallizes out in octahedral crystals, which in form and taste are not to be distinguished from common alum. These crystals are generally colourless, but sometimes have an amethyst tint, which arises from their containing a trace of ferric acid.—HEINTZ. Potash-iron alum is not stable at temperatures above 32° Fahr. (0° C.), and is decomposed wholly at 212° Fahr. (100° C.).

Lime in the ores is most prejudicial, since it deprives the aluminium and ferrous sulphates of their sulphuric acid, and thus entirely stops the production of alum; ores containing any considerable quantity of lime cannot consequently be used in this manufacture. Gypsum, however, is always found in the crude lies. Magnesia is no less deleterious to the formation of alum, but the magnesium sulphate—Epsom salt—thus produced is in some of the English alum-works regarded as a most important object. Fresh alum ores contain no soluble salts of aluminium or iron; it is only where air has had access to them, either in the pit or at the surface, that efflorescence in the form of fine needles—feather alum—is observed, and this consists partly of real alum, partly of aluminium sulphate, or of combinations of the latter salt with ferrous oxide, magnesium sulphate, or other salts.

An aluminous iron sulphate occurred abundantly some years ago in the Hurlet and Campsie wrought-out coal beds, which had the following composition:—

	Berthier.	Phillips.	R. D. Thomson.	R. D. Thomson.
Sulphuric acid,	34·40	30·90	35·600	28·635
Ferrous oxide,	12·00	20·70	13·560	19·935
Alumina,	8·80	5·20	7·127	2·650
Magnesia,	0·80	—	—	—
Water,	44·00	43·20	43·713	48·580
	100·00	100·00	100·000	100·000

The composition of this feather alum, or *hair-salt*, as it is sometimes termed, is shown by the subsequent analyses. The term hair-salt, sometimes given to these natural effloresced bodies, belongs properly to the magnesium sulphate often accompanying them.

COMPOSITION OF NATURAL ALUMINIUM SULPHATE—FEATHER ALUM ($Al_2(SO_4)_3,18H_2O$).

	Saldana.	Pasto.	Pyromeni, in Island Milo.	Coquimbo, Chili.	Kolosorak, Bohemia.	Friersdorff, near Bonn.	Potschappel, near Dresden.	Freienwalde.	Ararat.	Andes.	Campsie, Glasgow.
	Columbia.										
Sulphuric acid,	36·400	35·68	40·31	36·97	35·82	37·380	35·710	35·637	58·58	35·872	40·425
Alumina,	16·000	14·98	14·98	14·63	15·57	14·867	12·778	11·227	38·75	14·645	10·482
Sesquioxide of iron,	0·004	—	—	2·58	—	—	—	—	—	0·500	8·530
Protoxide of iron,	—	—	—	—	—	2·463	0·667	·718	$\left.\begin{matrix}SO_3\\FeO\end{matrix}\right\}$ 2·78	—	—
Protoxide of manganese,	—	—	—	—	—	—	1·018	0·307	—	—	—
Potassa,	—	—	0·26	—	—	0·215	0·324	0·430	—	—	1·172
Soda,	—	—	1·13	—	—	—	—	—	—	2·262	--
Lime,	0·002	—	—	—	—	0·149	0·640	0·449	—	—	—
Magnesia,	0·004	—	0·85	0·14	—	—	0·273	1·912	—	—	—
Hydrochloric acid,	—	—	0·40	—	—	—	—	—	—	—	—
Silica,	—	—	1·13	1·37	—	—	—	0·430	—	0·100	—
Water,	46·600	49·34	40·94	44·64	48·61	45·164	47·022	48·847	—	46·375	36·295
Loss,	0·990	—	—	—	—	—	1·568	·043	—	0·246	3·096
	100·000	100·00	100·00	100·33	100·00	100·238	100·000	100·000	100·11	100·000	100·000
	Boussingault.		Hartwell.	H. Rose.					Gobel.	T. Thomson.	

The manufacture of alum from alum schists may be distributed under the six following heads:—

Preparation of the alum shale.

Lixiviation of the roasted shale.

Evaporation of the lixivium.

Addition of the saline ingredients to precipitate the alum.

Washing of the aluminous salts.

Crystallization.

Preparation of the Alum Shale.—Roasting or Ustulation.—Some alum slates are of such a nature that, when piled in heaps in the open air, and moistened from time to time, they become hot spontaneously, and by degrees fall into a pulverulent mass, which is fit for lixiviation. The greater part of the ores, however, require the roasting process. By roasting the cohesion of the dense slates is so much impaired that their disintegration becomes more rapid; the decomposition of the pyrites is quickened by the expulsion of a portion of the sulphur; and the sulphate of iron already formed is partly decomposed by the heat, and transfers its sulphuric acid to the clay, producing aluminium sulphate.

Such alum shales as contain too little bitumen, or coal, for the roasting process, must be interstratified with layers of small coal or brushwood. The fuel being kindled, the whole slowly ignites. More rock is piled upon it, until in some instances a vast heap of inflamed material, 100 feet high and 200 feet square, is raised, which continues to burn for months. When the heap is fired with brushwood, the ash, containing potash, gives rise to the formation of small quantities of alum.

Alum is manufactured at Whitby by the combustion of the schists of the upper lias, which contain a quantity of iron pyrites and bituminous or carbonaceous matter. The temperature being regulated and water occasionally supplied, decomposition occurs, producing sulphates of alumina, iron, and magnesia, as follows:—

$$4FeS_2 + Al_2O_3 + MgO + O_{28} + 32H_2O = 4(FeSO_4,7H_2O) + Al_2(SO_4)_3 18H_2O + MgSO_4,7H_2O.$$

In Rhenish Prussia, especially at Salzweiler, roasting is effected by the aid of a stratum of brown coal beneath it, which has continued in a state of restricted combustion ever since 1660, when it was accidentally ignited.

A clay bottom is best adapted for the erection of a heap, as it prevents any of the salts being carried by the moisture into the soil; the heap is also sometimes constructed under a shed. As a general rule, the slower and more uniform the heat during the calcination the better the produce.

The Scotch alum-works are those of Hurlet and Campsie—the former six miles south from Glasgow, the latter about nine miles north of the city, at the foot of the Campsie Hills. The aluminous shale found in this locality is interstratified between the coal bed and the limestone, and is nearly as dark-coloured as the former; it is occasionally found mixed with native crystals of sulphate of iron. After the shale has been exposed to the air for some time, the black colour is replaced by a grey, owing to the action of the air causing it to throw out a white efflorescence of alum.

A striking appearance is presented by the alum-field, which is covered throughout with ridges or elongated mounds of the ore for calcination, or already calcined, and these assume a reddish-brown hue from the effect of the heat. The heaps vary in size, and contain from 6000 to about 20,000 tons each. At one of the works under consideration, there are about 15 of the mounds or ridges of shale, each being 120 to 180 feet in length, with a base of about 20 feet, and a height of 15.

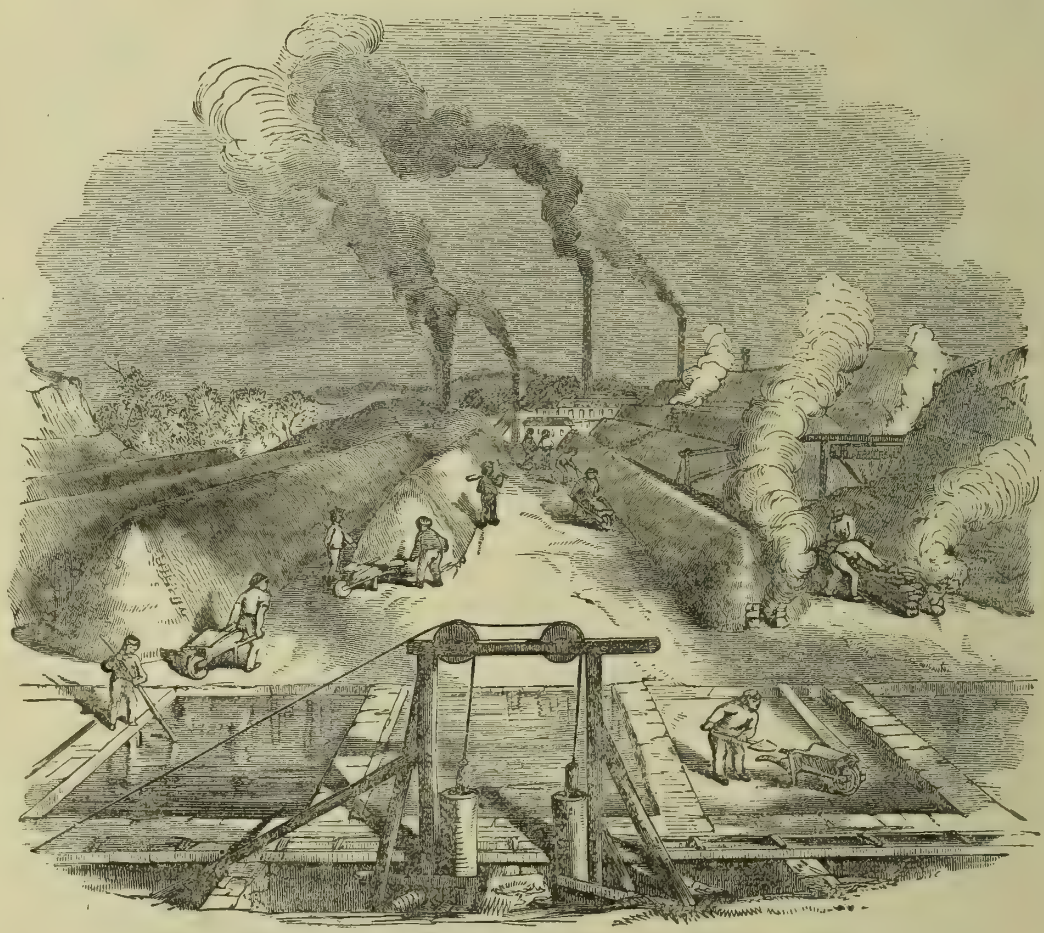
Fig. 2 shows the arrangement of the field.

The mounds are commenced by making a few fires of coal along the intended length, and covering them over with stones or bricks in any convenient manner, leaving lateral ducts, or passages, for the air to enter. The shale is then thrown on the fires, the coarsest first; and as it ignites, and communicates heat to the outer portions, more of the mineral is thrown upon it successively, until the heap is considered large enough, the whole being kept at that state of ignition which practice leads the manager to judge most advantageous. It is then *mantled*, as the workmen term it, that is, covered over with a layer of the already calcined and exhausted ore, in order to protect it from high winds and excessive rains, and also to moderate the heat and let it cool gradually, so that the sulphur present may not be volatilized or sublimed. From three to twelve months, according to the state of the weather, are generally required to calcine the heap properly; in rough weather very little progress is made. This time includes the period of cooling the burned ore, which is done either by leaving the heap to itself, or checking the roasting by applying a thicker mantling.

The several mounds are so arranged that they may be in various stages of advancement, some being cold, others about to be mantled for cooling, many in progress, while a further number are commencing, so that at all times a supply of calcined shale may be ready for the liquefying vats.

At Whitby the calcining heaps are raised from 80 to 100 feet in height. In consequence of the greater amount of carbonaceous matters which the shale at these works contains, the temperature of the mounds sometimes rises too high, and causes the loss of much sulphurous acid; this may be partly prevented by mixing the shale with some of the calcined and exhausted ore, and when the heap has acquired a larger size, if the heat is still deemed too high, either plastering up the crevices with small schist, or mantling over the whole as at Hurlet.

Fig. 2.



About 130 tons of the Whitby calcined schist yield one ton of alum. In this country it is found advisable to pile up on the top of the ridge of brushwood or coal and schist, a pyramidal heap of the mineral, which, having its surface plastered smooth with only a few air-holes, protects the mass from the rains, and at the same time prevents the combustion from becoming too vehement. Should heavy rains supervene, a gutter must be scooped out round the pile for receiving the aluminous mother liquor, and conducting it into the reservoir.

A continuous but very slow heat, with a smothered fire, is most appropriate for the roasting of alum shale. When the fire is too brisk, the iron sulphide sometimes forms with the earthy matters a species of slag, or the sulphur is dissipated in vapour, either of which accidents causes a deficiency in the produce of alum. Those bituminous schists which have been used as fuel under steam boilers have suffered such a violent combustion that their ashes scarcely yield any alum. Even the best regulated calcining piles are apt to burn too briskly in high winds, and under such circumstances should have their draught-holes carefully stopped. It may be laid down as a general rule that the slower the combustion the richer will the roasted ore be in aluminium sulphate. When the calcination is complete the heap is diminished to one half its original bulk; it is covered with a light reddish ash, and is open and porous in the centre, so that the air circulates freely throughout the mass. In order to favour access of air the masses should not be too elevated; and in dry weather a little water should be occasionally sprinkled on them, which, by dissolving some of the saline matter, renders the interior more open to the atmosphere.

When the calcined mineral is thoroughly cold it is taken to the lixiviating vats. Since many weeks, or even months, may elapse from the first construction of the piles or beds till their complete calcination, care should be taken to provide a sufficient number of them in different stages, so as to have an adequate supply of material for carrying on the lixiviating and crystallizing processes during the course of the year. The complete decomposition of the beds is judged of by the efflorescence of the salt, by the strong aluminous taste of the ashes, and by the appropriate chemical test of lixiviating an aliquot average portion of the mass, and seeing how much alum it will yield with a solution of potassium sulphate or chloride.

Spence calcines the shale by forming on the ground a number of air-channels, on which are laid parallel lines of common bricks at the distance of four inches apart, on these others are placed crosswise; thus the channel formed is about four inches square. The transverse bricks are placed on loosely, so as to allow the air to pass freely upwards; burning coals are laid on the channels, and a layer of the shale which is most bituminous, broken into small pieces; and as the combustion proceeds other layers of the shale fragments, less bituminous than the preceding, are put on continuously, but not in too great a quantity. The thickness of each layer is regulated by the briskness of the combustion, which should never go beyond a low red heat, as a higher temperature would be apt to partially flux the materials, thus rendering the alumina less soluble in the sulphuric acid. The blaze, candle-slates, and other bituminous shales and fire-clay stones, are first broken into lumps about the size of the stones used in road-making. If clay stone be the substance under treatment small coal, or sawdust, must be mixed through it to insure perfect calcination. An examination of the preceding figure, exhibiting the heaps or mounds in various stages of progress, will show that a method similar to this is practised at Hurlet.

The heaps may be made of any convenient dimensions, but the height most appropriate is 4 to 5 feet. The mass will burn out, and be cool enough for use in eight or ten days.

Wilson selects shale as free as possible from impurities, and after exposing it for three or four months to the action of the atmosphere, by which it breaks down and assumes a pulverulent form, roasts it in a lime kiln of the ordinary construction, in which continued removals of roasted shale are effected below, and continued additions of new shale are made in the upper part of the kiln, care being taken to avoid fluxing.

Lixiviation of the Roasted Ores.—This part of the operation for dissolving out the aluminium sulphate and other soluble components, is one which requires much attention. The amount of water must be so regulated as to extract the whole of the soluble bodies, without having a superabundance of liquid to eliminate when the solutions are to be concentrated for precipitation or crystallization. When an excess of water has been employed to exhaust the calcined shale much time and labour are required for the evaporation. Hence, only so much water should be employed as is necessary to exhaust the ore of its soluble saline ingredients. Vessels for the lixiviation are either wooden tanks lined with sheet-lead, or cisterns made of stone; the latter are more durable, but more expensive. The lixiviating vessels are in England and France placed at different levels, for the purpose of facilitating the exhaustion of the material in them, while in Scotland they are constructed upon the same plane. The form usually given to these vessels is that of a square or oblong.

When the exhaustion of the roasted shale is effected by the first of these arrangements, as at Whitby, a wooden or iron sluice carries the lie from the series of tanks to a large cistern to be again returned upon the upper troughs, recharged with fresh portions of the burned ore, in order to bring it to the proper degree of strength, when it is drawn off to be concentrated by heat. Water is let into the upper troughs through several inlets, till it covers the burned material to the depth of one or two inches. After six to twelve hours, according to the facility with which the sulphates are extracted, the liquor from this tank is drawn off at the openings at the bottom into the cistern next beneath it, where it is suffered to remain for an equal length of time before it is run into the clarifying vessel, whence it is conducted to the pans for evaporation. No more than half the water employed in the first washing can be drawn off, as nearly half is retained by the shale: and in consequence of this only half the quantity of water used in the first is added to make the second lie, which, after twelve hours, is drawn off into the lower cistern, like the preceding, and a third quantity of water is poured on in order to extract the whole of the soluble ingredients. This third washing being of a low strength is pumped up to form the first watering of fresh quantities of the material, to bring it to the desired strength for evaporating, which should be from 1·113 to 1·157 specific gravity.

At the Hurlet and Campsie Works, near Glasgow, the process pursued is the following:—After the ore is calcined it is wheeled from the ridges into large stone cisterns, called *steeps*, occupying the same level—see Fig. 2. The steeps are furnished with false bottoms formed of planks, which rest on transverse beams, and the roasted shale is laid on the planks till it is about 18 inches above the bottom. Water, or a weak lie from a previous operation, is poured upon the bed of ore till it is completely covered over, and allowed to remain in contact with it for about eight hours, generally through the night. A plug at the bottom of the vat is then opened, and the solution, which should have a specific gravity of about 20° Twaddle, or 1·100 specific gravity, is drawn off into the *settler*, or supply cistern, where it is allowed to remain at rest, in order that any matters held mechanically may subside. A second wash of a weaker liquor than that employed in the first operation is then added, and left in contact with the partly-exhausted shale as long as in the first instance, after which it is drawn off to the cistern as before; the same operation is repeated a third time if necessary, till the liquid becomes below 12° Twaddle in strength, after which it is not deemed economical to evaporate for alum, the further washings being used for exhausting fresh quantities of ore. The last washings of the steep are made with water, and the strongest of the several resulting weak liquors from each steep is used the first in exhausting a fresh one. After the ore is deprived of its soluble ingredients, it is either removed to the waste heap, or returned to the calcining ridges, where it is intermixed with the fresh ore for the purpose of checking a too rapid combustion, when such is apt to take place.

At Valmunster, in the department of the Moselle, the tanks are constructed of burned stones and clay, and each has a capacity of 1728 cubic feet—1380 cubic feet Rhenish. At the bottom, at certain distances from each other, beams are arranged, upon which a layer of straw and brushwood is laid, and upon this the false bottom of boards is placed. This arrangement forms the filtering apparatus, from which the lie flows through apertures at the sides. Each cistern requires 1280 cubic feet of water for the lixiviation. Lie is first poured upon the ore of 20° B. = sp. gr. 1·157; when this has run off it corresponds to 24° or 25° B., and is fit for boiling; a weaker lie of 15° B. = sp. gr. 1·113, and subsequently others of 10° B., = sp. gr. 1·072, and the weakest of 5° B., = sp. gr. 1·034, then follow; and lastly, the whole is washed out with pure water. All the lies that fall short of 24° or 25° B. are poured upon more or less exhausted ores, according to their strength. By arranging these cisterns upon terraces, the one above the other, the lie can easily be drawn from the upper into the lower cisterns, until it has acquired the proper strength. The solution is then called crude liquor, and is preserved in large walled tanks, ready for further operations.

The density of the liquors is determined by a specific gravity bottle peculiar to the alum manufacturers; it is capable of containing 80 pennyweights of water at the ordinary temperature, and when this bottle is filled with the alum liquor and weighed, the excess of weight is denominated the strength in pennyweights; thus, if a liquor should weigh 90 pennyweights, it would be put as one of 10 pennyweights, or simply liquor of 90. A similar method is the use of the hydrometer, for determining the amount of ingredients dissolved, and this even in the pennyweights of the alum-maker; thus, dividing the indications of Twaddle's hydrometer by 2·5, gives the alum-maker's strength in pennyweights, without the trouble of weighing.

According to SCANLAN, eight different liquors are met with in the alum-works on the Yorkshire coast.

1. *Raw liquor.*—The calcined alum shale is steeped in water till the liquor has acquired a specific gravity of 9 or 10 pennyweights, according to the language of the alum-maker.

2. *Clarified liquor.*—The raw liquor is brought to the boiling point in leaden pans, and suffered to stand in a cistern till it has become clear; it is then called clarified liquor. Its gravity is raised to 10 or 11 pennyweights.

3. *Concentrated liquor.*—Clarified liquor is boiled down to about 20 pennyweights. This is kept merely as a test of the comparative value of the potassium salts used by the alum-maker.

4. *Alum-mother liquor.*—The alum pans are fed with clarified liquor, which is boiled down to about 25 or 30 pennyweights, when a proper quantity of potassium salt in solution is mixed with it, and the whole run into coolers to crystallize. The liquor pumped from these rough crystals is called *alum-mothers.*

5. *Salt-mothers.*—The alum-mothers are boiled down to a crystallizing point, and afford a crop of *rough Epsom*, which is magnesium sulphate with ferrous oxide.

6 and 7. *Alum-washings.*—The rough crystals of alum—No. 4—are washed twice with water, the first washing being about 4 pennyweights, the second about 2½, the difference in gravity being due to mother-liquor clinging to the crystals.

8. *Tun-liquor.*—The washed crystals are now dissolved in boiling water, and run into the roching-tuns—wooden vessels lined with lead—to crystallize. The mother-liquor of the *roch-alum* is called *tun-liquor;* it is of course not quite so pure as a solution of roch-alum in water.

With reference to the exhausted residues, two cases may occur: they have either been rendered perfectly porous by the roasting and decomposition, in which case they will have been completely exhausted, and may be thrown away unless they can be used for covering fresh heaps; or they still contain portions of undecomposed ore, and may then be subjected to a second exposure—as at Buchsweiler, in Alsace—either by themselves or mixed with fresh ore.

The process in many other alum-works, where the ores do not require roasting, is essentially the same as that described above. The lixiviation, however, is then carried on with the heaps themselves, and during the process of decomposition; they are erected for this purpose either upon flat wooden boxes, termed Bühnen, or upon a foundation composed of brick-work or clay, which is completely impervious to the liquor, and where the water which is pumped from time to time upon the heap collects, and is thence conducted to the crude liquor cisterns. The soluble salts are thus removed at certain periods, as they are produced during decomposition. The strength of the crude liquor in the cistern must be regulated by the respective prices of labour and fuel, weak liquor requiring more fuel, and strong liquor more labour; it is never advisable, however, to concentrate the liquor to the degree at which it would be saturated with crystallizable salts, such as green vitriol and sulphate of magnesia, as these would crystallize with the slightest amount of evaporation or rise of temperature before it was desirable they should do so. In general, the density indicated by 20° B., = sp. gr. 1·157, is not exceeded. Simon found the crude liquor from Gleissen, in Neumark, to contain the following ingredients:—

Aluminium sulphate,	11·085	= 29·678
Ferrous sulphate,	9·773	
Sodium sulphate,	2·035	
Magnesium sulphate,	1·754	
Manganese sulphate,	0·174	
Potassium sulphate,	0·095	
Sulphate of lime,	0·120	
Sesquichloride of iron,	1·872	
Magnesium chloride,	0·334	
Aluminum sesquichloride,	0·419	
Sulphuric acid,	0·563	
Hydrochloric acid,	1·454	
Water,		70·322
		100·000

These constituents are always accompanied by a certain quantity of ready-formed alum, which may be potash or ammonia alum, or both, if a red heat has not been employed in the manufacture; but if a high temperature has been applied, both are decomposed, leaving only alumina. To the production of the potash alum, the alkali naturally contained in the ores contributes, and still more that which exists in the ash of the wood used as fuel; the production of ammonia is attributable to the nitrogen contained in the coal. During the time that the crude lie is clarifying in the large vats, a chemical decomposition ensues by the action of the air upon the ferrous sulphate, which is not prevented by the state of solution of the salt.

In the foregoing analysis nearly the whole of the oxide of iron is precipitated, and only a very small portion remains in solution. This behaviour is turned to account by mixing the crude liquor with the mud obtained in a subsequent operation. This mud is a kind of basic alum, which is soluble and deficient in a certain quantity of, but does not contain enough sulphuric acid to make alum. The basic sesquisalt of iron is called in German *vitriolschmand*, and is collected from time to time from the bottom of the cisterns, and heated to redness; it then parts with its acid, and the peroxide remains, which is used as a red pigment.

Boiling the Crude Lie.—The further treatment of the lie depends upon the quantity of green vitriol which it contains, and in most cases there is quite as much of this salt as of alum. When this happens the lie is used for the production of both salts, and alum and copperas works are generally carried on conjointly. The process of separating the two salts by crystallization varies much in different manufactories.

When, however, the quantity of ferrous sulphate is too small to admit of being profitably extracted, the liquor is at once evaporated until it has attained the specific gravity 1·40. Basic sulphate of iron is deposited, and the liquor assumes a brick red colour. In order to clear it, it is run off into tanks, and after the suspended matter has deposited is syphoned off and transferred to the precipitation tanks.

When the crude lie is very much charged with the iron salt it is evaporated in pans, into which old iron is thrown. The ferric oxide formed by the action of the air is thereby partly precipitated as a basic salt, and the sulphuric acid set free converts a part of the iron into sulphate, hydrogen gas being at the same time given off. The latter reduces the precipitated ferric sulphate to ferrous sulphate, and prevents its further oxidation during the evaporation.

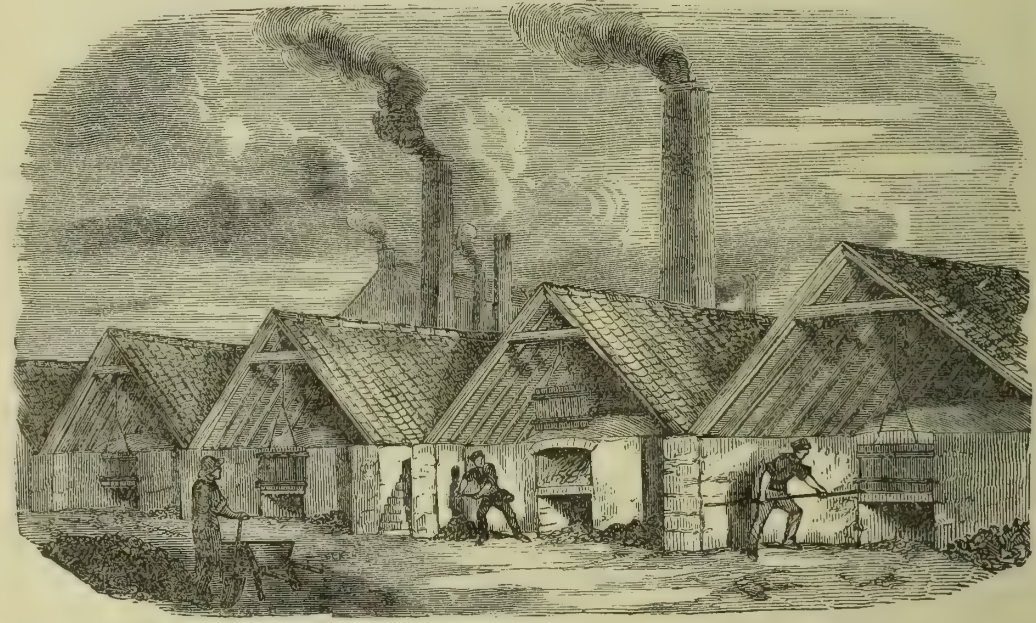
In order to afford more points of attachment for the crystals and facilitate their removal, the workmen hang peeled sticks and branches in the solution. The mother lie contains the whole of the sulphate of alumina, which is separated in a manner to be subsequently described.

In other places—as at Reschwitz, near Saalfeld, at Schwemmsal—the greater portion of the water is removed by causing the liquor to trickle through skeleton towers filled with brushwood placed in a strong draught, as in the salt-works, when, in consequence of the increased action of the air, a considerable portion of the green vitriol is decomposed, and much basic sulphate of iron, mixed with gypsum, is left as an incrustation upon the thorns. The concentrated lie then yields green vitriol on evaporation, and the mother liquor contains the alum.

Another process consists in separating the copperas, not by cooling the saturated solution, but by simple evaporation or abstraction of water. When evaporation has been carried on for some time, and the loss of water and the strength of the lie have reached a certain degree, a point of saturation is attained—when the specific gravity is from 1·35 to 1·37, or 38° to 40° B.—at which the remaining water is just sufficient to retain the copperas in solution. The evaporation of every additional quantity of water then causes the precipitation of a portion of copperas, and a sediment, consisting of very small anhydrous or slightly hydrated crystals, is rapidly deposited. In the meantime, the evaporated water is constantly replaced by fresh liquor. It is obvious that, upon this plan, in which the liquor is always saturated, the quantity of dissolved green vitriol cannot accumulate in the pan, whilst the amount of the other soluble salt, aluminium sulphate, must increase synchronously with the deposition of the former until the liquid is saturated with it. At this stage the liquor is carefully watched by means of the hydrometer, to avoid any supersaturation with aluminic salt, as in time it would precipitate with the ferrous sulphate. The precipitated sulphate of iron is then removed and purified by crystallization, when it acquires seven equivalents of water, and a mother liquid remains, saturated with aluminium sulphate, which is available for the production of alum.

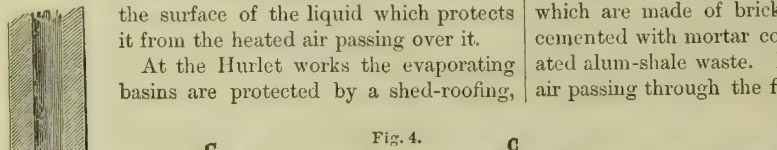
When, on the contrary, the copperas is not in excess, the process is reversed, and begins with the production of alum from the crude liquor. For this purpose the lie is pumped at once from the crude liquor cisterns, in which it has been clarified, into the evaporating pans to be brought to the proper degree of concentration. If the pans are made of tinned iron they will be corroded by the lie, with evolution of hydrogen and the precipitation of basic aluminium sulphate; this action is not prevented by the addition of the basic mud before mentioned. When cast-iron or leaden pans are employed, which are not thus affected, the sediment frequently gets burnt on the bottom, and causes difficulty and damage; but the former are brittle, and the latter are too easily melted by the heat. To prevent this burning metal evaporating pans are now, except under special circumstances, universally discarded, and the flame is carried over the surface of the liquid instead of below the pan. When, however, the liquors contain magnesium sulphate surface evaporation cannot be used, as when the concentration has proceeded to a certain extent the salts form a crust on the surface of the liquid which protects it from the heated air passing over it.

Fig. 3.



At the Hurlet works the evaporating basins are protected by a shed-roofing, as represented in Fig. 3. They are long cisterns of brickwork well cemented together, and arched over with the like materials; they have a length of 60 feet and a breadth of 6, with a depth of about 4; are capable of evaporating about 4500 to 5000 gallons in twenty-four hours. The cisterns are heated by a furnace, which is placed at one end, and on a level almost with the surface of the liquid when the boiler is full, as has been already described; a powerful chimney at the opposite end of the boiler creates a strong draught that sweeps the flame and heat from the fire over the surface of the liquor, producing a very high temperature, and rapid evaporation takes place. Fig. 4 represents a longitudinal section of one of these evaporating cisterns.

Fig. 4.



The liquor is placed in the basin, A A, the walls of which are made of brick, placed upright, and well cemented with mortar composed of lime and lixiviated alum-shale waste. In order that the current of air passing through the fire at D may not carry any appreciable quantity of the ashes into the liquor, the fire bars are fixed low down; the flame passes below the flat arch, B B, to the chimney. This arch contains apertures, C C, through which to observe the different parts of the interior. Fresh liquors, or the mother liquors from a previous operation, are introduced through the openings, C C, as the water is evaporated from the contents of the furnace, until the solution acquires a density of about 1·40, which is the most suitable state of concentration for producing the flour, or meal, for the next operation.

To economize fuel the furnace is very long, and the fire communicates with an evaporating pan, so that the whole heating power may be made available as far as practicable. The draught of the furnace insures, in the simplest manner, a constant current of air over the liquid, which is favourable to evaporation by sweeping the vapours generated onwards to the chimney. During the evaporation of the liquor in the furnace a copious sediment is thrown down, consisting of basic ferric sulphate, sulphate of lime, and other salts, of which it is necessary to clear the liquor in the cooling vats; but however impure the liquor, or however rich in aluminium sulphate the solution may be, its evaporation should not be carried on so far as to cause a deposition of salt upon cooling; the ingredients must be entirely held in the clear solution, even after cooling the liquor in the vats set apart for the production of the alum flour.

The furnaces are fired incessantly for eight days, and the boiler is replenished with liquor from the supply cistern till the eve of the eighth day, when a charge of mother liquor is run in which deposits no sedimentary matter on boiling, like the fresh liquor; this is boiled down till it has the proper degree of strength, and then allowed to settle for twelve hours. After adding the mother liquor it is customary to find the strength of the solution. This is done by taking out a known quantity of it, and concentrating it to the proper strength with potassium chloride and allowing the solution to cool for twenty-four hours; the crystals produced, when washed with a little cold water, dried and weighed, furnish an approximate test of the value of the liquor as to its real percentage of alumina. The alum-maker also employs this process to test the quality of his potassium chloride; but in the latter case he has a standard solution of aluminium sulphate. These experiments point out the quantity of alkaline chloride which should be added per gallon of liquor.

At the Whitby alum-works leaden pans are employed, in consequence of the liquors from the calcined shale of this locality containing sulphate of magnesia, which renders surface evaporation inapplicable, as already explained; the pans are 10 feet long, 4 feet 9 inches wide, 2 feet 2 inches deep at one end, and 2 feet 8 inches at the other. In these lead pans the liquor is rapidly concentrated by a fire at one end, the flue of which runs along in parallel channels under a plate or course of brickwork on which the pans rest. Every morning the pans are emptied into a settling cistern of stone or lead. The specific gravity of the liquor should be about 1·40 to 1·50; this density varies, however, according to the views of the manufacturer. For a liquor which consists of two parts of aluminium sulphate and one of ferrous sulphate, a specific gravity of 1·25 may be sufficient; but for a solution of one part of aluminium sulphate and two parts of sulphate of iron, which latter is to be abstracted by crystallization, a density of 1·40 is requisite.

Preparation of the Powder.—From the evaporating basins the liquor is run into the flour or powder cisterns, in which the aluminium sulphate is combined with potassa or ammonia (the "flux" or "precipitating substance"), in such a manner as to effect the first purification of the alum. The alum is only very slightly soluble in the cold mixture of the liquor with the solution of the precipitating substance, and for this reason the greater portion of it separates in the form of minute crystals, or "flour," from the solution; an agitating motion given to the liquor in the cisterns favours the formation of the crystals. To obtain the largest yield of flour it is necessary for the precipitating solution to be as strong as possible, which is secured by dissolving the precipitant in the least possible quantity of boiling water. The proper amount of the precipitant should be determined, as near as possible, by a preliminary experiment on the small scale; but still these data, though they serve to give an idea of the quantity, do not correspond always with the extensive operations of the manufacturer; so that even when previous experiments are made to ascertain the true quantity to be added, much caution is necessary when operating on the whole bulk of mother liquor, as an excess of the precipitant may often cause much future inconvenience and labour. The best precipitating substances are potassium and ammonium salts, as these form alums which are very insoluble in cold water, only 9·25 parts of the potassium alum, and 9·16 parts of the ammonium alum being dissolved by 100 parts of water at 50° Fahr. (10° C.). Sodium salts are very disadvantageous precipitating agents in the formation of alum, on account of the great solubility of the resulting compound, 46 parts of which are dissolved by 100 of water at 50° Fahr.; they are therefore seldom used.

In the event of potassium salts being employed, preference is given to potassium chloride or sulphate; of the latter 50·9 parts are required to precipitate 100 parts of aluminium sulphate, from which results 334 parts of crystallized alum. The preceding enumerated tests, however, will not answer in the factory, because the mother liquor is indefinite as to the amount of impurities which accompany the aluminium sulphate. To show this more clearly, let it be supposed that the mother liquor is saturated with ferrous sulphate and aluminium sulphate, and that its temperature is 50° Fahr. In this case it will contain, for every

100· parts of water,
33·2 parts of anhydrous ferrous sulphate, and
33·5 parts of anhydrous aluminium sulphate.

To precipitate these products 17·1 parts of neutral potassium sulphate are required, for the solution of which 66 parts of boiling water will be necessary.

On mixing this solution with the lie, 96 parts of alum will be produced, together with the accumulated water of the lie and precipitant, which, collectively, will amount to 166 parts. Of the 96 parts of alum formed, only 16 can remain in solution after the liquor has cooled to the primary temperature of 50° Fahr. (10° C.); therefore 80 parts will separate in the crystallized state; but in practice this quantity diminishes according to the less saturated state of the lie. Since potassium chloride is more soluble in boiling water than potassium sulphate, it is preferable for precipitating the alum flour; the chloride is soluble in 2 parts of boiling and in 3 parts of cold water, and hence the mixture may be made in the cold.

In the instance cited above the 33·5 parts of aluminium sulphate would require 14·5 parts of potassium chloride for precipitation, which would be taken up by 26·2 parts of boiling water, and produce 96·5 parts of alum.

The mixture being made and the precipitate subsided, 12 parts of the alum would be held in solution, so that only 84·5 parts of flour are thrown down in the solid form. If the same quantity of potassium chloride be dissolved in cold water, 46 parts at 50° Fahr. (10° C.) will be required, which, when added to the 23·5 parts of aluminium sulphate in solution, will yield 84 parts of alum as a precipitate, while 13·8 remain dissolved: in both cases the difference is immaterial, whether the precipitant be dissolved in hot or cold water.

Another precipitant which is used with much advantage on account of its great solubility, is ammonium sulphate: this is soluble in 2 parts of water, but the amount of alum obtained is less than when the potassa salts are employed, in the proportion of 100 : 95·6; the reason being that the atomic weight of these bodies differ, the equivalent of ammonium hydrate, $(NH_4)_2$, used being 36, while that of potassium is 39·1.

To recur to the foregoing example, the 33·5 parts of aluminium sulphate will take 15·8 parts of ammonium sulphate to form with them 87·7 parts of alum, of which 77 parts are precipitated and only 10·6 retained in the solution; thus, the disadvantage arising from the lesser equivalent of ammonia alum is counterbalanced by the greater solubility of the ammoniacal salt as a precipitating agent.

The potassium sulphate, for the use of alum-makers, is obtained as a secondary product in the manufacture of nitric acid, and in the purification of potassium hydrate and the crude carbonate of that alkali: thus produced it is an acid sulphate, commonly called bisulphate of potash, the composition of which is expressed by the symbols $KHSO_4$, and cannot be employed for alum making till the excess of acid is neutralized by fresh additions of the caustic or carbonated alkali to form a neutral or bipotassic sulphate of the composition, K_2SO_4.

It is only under the above circumstances that potassium hydrate or carbonate can be employed in the preparation of the alum flour; for if no free acid is present it throws down a basic double sulphate of aluminium and potassium which is insoluble in water, though redissolved by a further addition of bisulphate of potash. A greater or less quantity of this compound is always formed during the evaporation of the liquors, in consequence of the iron present abstracting some of the acid, but, as in the preceding, a slight addition of the bisulphate of potash redissolves it.

Knapp recommends that the purification of crude potassium hydrate and carbonate should be conducted on the same premises with the alum works, for the purpose of turning to use the bisulphates and chloride formed in this operation as precipitants of the alum. With regard to the latter salt, he says it is of greater importance than the sulphate, inasmuch as it effects the decomposition of the sulphates of iron, giving rise to potassium sulphate and chlorides of iron, which are highly deliquescent salts, and from which the alum flour can be removed with greater ease than from the sulphates of iron. But the decided advantage attending the use of the chloride is when a ferric sulphate is present in the lie, as this latter salt, in combination with potassium sulphate, forms a difficultly soluble double salt (basic iron alum), which precipitates in the form of a yellow powder, and contaminates the alum flour. As an excess of potassium chloride would convert the aluminium sulphate into aluminium chloride, a result which would entail a loss, he recommends that the lie should be examined before each operation, with a view to determine the proper amount of chloride to be added, as it happens that the quantity required to precipitate the whole of the aluminium as alum seldom or never meets with sufficient ferrous sulphate in the lie to be converted into potassium sulphate. This examination is conducted as follows:—A saturated solution of the precipitating salt is added from a burette, or other graduated vessel, to a measured quantity of the liquor, the mixture being briskly agitated at each addition; successive portions of the reagent are poured in as long as the flour thrown down increases in quantity, and when no further precipitation is observed the number of measures is read off, which, with sufficient accuracy on the large scale, will stand for the amount of solution required to precipitate a certain amount of the liquor; by this means the tedious process of weighing is avoided. If potassium sulphate has been employed, from its difficult solubility in the cold it may precipitate during the cooling of the liquor, apparently increasing the bulk of the precipitate, and giving rise to an error in the calculation. To avoid this source of inaccuracy it is best to employ, as the testing liquor, a saturated solution of ammonium sulphate, which, being very soluble both in hot and cold water, is not precipitated. One part of the ammoniacal salt is equivalent to 1·32 parts of potassium sulphate, or 1·13 of potassium chloride.

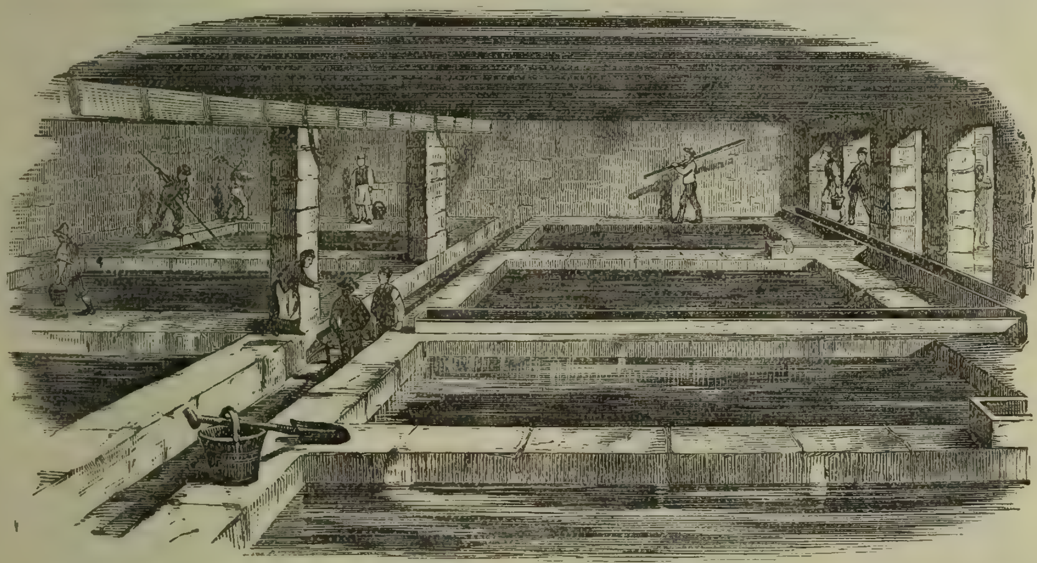
Potassium chloride for alum making is obtained in large quantities from the waste liquor of the soap works, from saltpetre refineries, and from the glass-houses. Wood ashes should never be used, on account of the lime which they invariably contain.

The ammoniacal reagent is obtained from the liquor from gas works; this is converted into ammonium sulphate either directly by the addition of sulphuric acid, or by treatment with sulphate of lime or iron. The crude ammoniacal liquor obtained from the manufacture of ammonium chloride, by the destructive distillation of animal matters, may be employed with equal advantage for the same purpose.

Having prepared the aluminous liquor, and ascertained the amount of salts contained per gallon, the crystalline flour is precipitated by gradually adding to the aluminous liquor the concentrated solution of the precipitant, the mixture being kept briskly agitated till the whole of the powder is thrown down. A slanting plane is fixed adjacent to the precipitating vessels, on which the workmen shovel the subsided powder, for the purpose of freeing it from the impure mother liquor of the vessel; the portion of lie adhering to the crystals drains off, and runs back to the mother liquor; still it does not wholly separate by this means, a small portion being mechanically retained by the mass of powder, which produces the brownish-yellow colour of the crystals after the first draining. To remove the colour recourse is had to another process called "washing." For this, it is sufficient to stir the powder with a small quantity of water in an appropriate tank or vat. The impurity mixed with the crystals is taken up by the water, as likewise a small portion of the alum, and when the substance has subsided the liquor is drawn off by means of a siphon; two washings are found sufficient to separate all adhering foreign soluble bodies. The water employed in washing the flour should be of as low a temperature as possible, as the quantity of alum dissolved out is in proportion to the temperature of the water.

Fig. 5 is a view of the precipitating and crystallizing cisterns at one of the Hurlet works; they are constructed of stone, well adjusted and embedded in tempered clay, on a site contiguous to the evaporating furnaces. Having ascertained the quantity of sulphate of alumina per gallon in the concentrated liquor in those boilers, their whole bulk of lie is found by gauging, at the temperature of 60° Fahr. (15°·5 C.). A corresponding amount of potassium chloride, or ammonium sulphate, is then weighed out and placed in one of the cisterns, after which the plug is removed from the boiler, and the liquor conducted along stoneware gutters to the coolers till it flows upon the heap of chloride. Sometimes the latter is gradually added to the liquor as it flows along in the gutters. Towards the end the mixture is well agitated to insure a complete solution of the alkaline salt and a uniform state of the liquor. In four or five days, when the plug is drawn out from the cistern and the mother liquor run off, the bottom and sides of the cooler are found lined with crystals of alum, generally some inches in thickness. This is called *first alum*, and is removed from the vessel to the draining stage, which is a raised platform in a sloping position, so that the mother liquor drains off from the heap, as shown in Fig. 6.

Fig. 5.



The first alum, when drained, is washed to remove as much of the mother liquor from it as possible. For this purpose tubs are filled with second alum mothers, or liquor which has been used in washing in a subsequent part of the process; and the alum, placed in wooden sieves, is rinsed in this liquor, and thrown on the stage.

The second alum boiler, which is a deep stone cistern covered with wood, Fig. 7, is then prepared by running in a quantity of liquor which had been previously used in washing the second alum; steam is next introduced, till the liquor has nearly attained its boiling point, when the washed and drained crystals are thrown in, and constant agitation kept up. This is continued till as much alum has been added as will increase the specific gravity to 60° Twaddle, and the temperature is raised as much as possible by the steam, which is then shut off, and the boiler being closely covered up, the liquor is allowed to remain at rest for twelve hours, for all the impurities to settle; the plug is then removed, and the clear liquor runs off to the second alum coolers, which, like the preceding, are sunk stone cisterns. In these it remains for four or five days, when the sides and bottom are found lined with alum, now nearly white, to the thickness of 8 or 9 inches. The small cup-like clusters of second alum crystals, which form on the surface of the coolers at this stage of the process, and successively fall to the bottom, assume the beautiful appearance exhibited in Fig. 8. The mother lie, which should have a specific gravity of 26°, is removed, and used for washing up the first alum as already described; and the crystals being broken up, are rinsed with pure water and drained, previous to the finishing process.

Fig. 6.

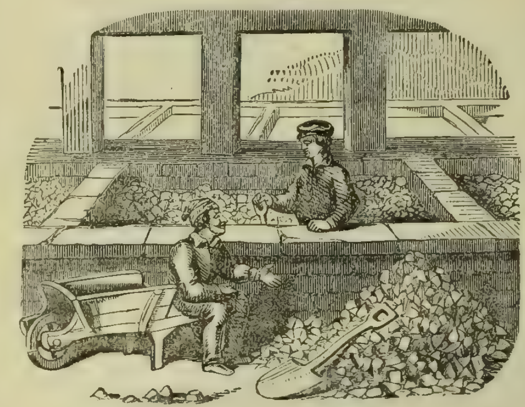
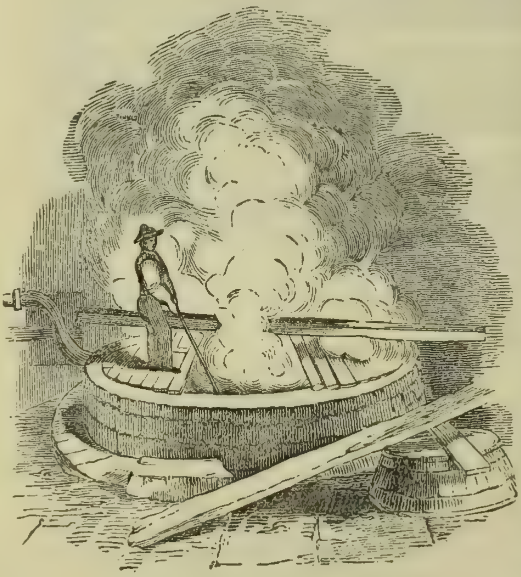


Fig. 7.

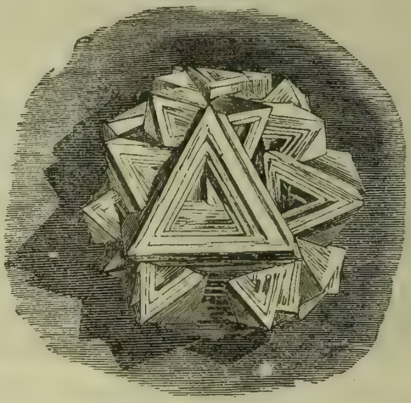


Crystallization.—The powder or alum flour, consisting of minute or imperfect crystals, prepared as just mentioned, is very seldom sent into the market, the consumers preferring to use the salt in the form of large crystals, the alum being less liable to be adulterated with any other impurities when in a well-defined crystalline state than when it is amorphous.

Crystallization of the alum flour is effected by dissolving it in as little boiling water as possible, and when no more of the substance is taken up, running the saturated solution into crystallizing vessels, which are denominated "roching casks," or "growing vessels." Steam is better adapted than water for the purpose of dissolving the flour. A large wooden vessel, lined with sheet-lead, is provided for this purpose, and in the interior the powder is sustained occasionally on perforated shelves, so that the steam which issues from the pipe that enters at the bottom may have more extensive contact with it, and thus dissolve it more readily. As the steam penetrates through the several diaphragms bearing the powder, part is dissolved; that which is liquefied in the upper ones is concentrated by the hot steam as it falls down to the bottom of the vessel, and being hot, it is at once run into the vessels for crystallization.

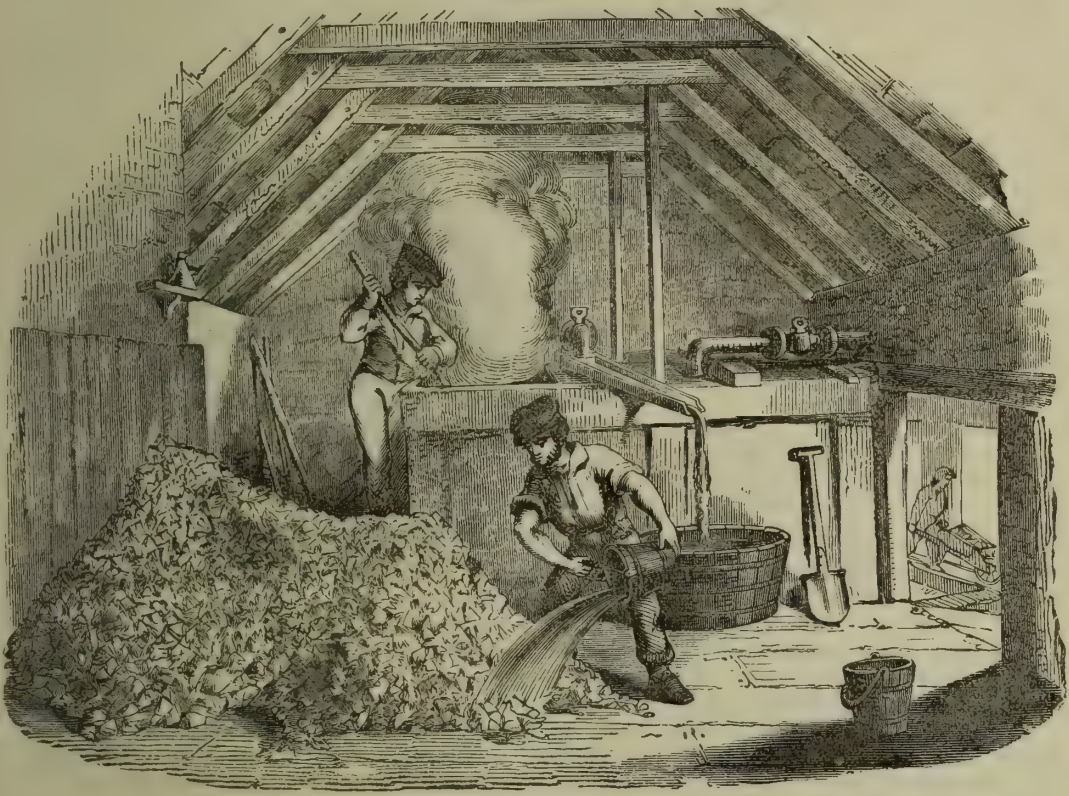
Fig. 9 is a drawing representing the roching-pan as it is usually found in the alum factories of England and Scotland; it works on the above principle, and therefore renders a subsequent evaporation unnecessary. It is a large covered leaden cistern, into which steam is forced, and the alum is shovelled in to meet it; a solution takes place rapidly, without any addition of water. The temperature of this solution having reached 96° Fahr. (35°·5 C.), the heat is raised as high as possible, generally to 224° Fahr. (106°·6 C.); and the steam being shut off, the pan is closely covered up, and allowed to remain at rest for four or five hours, or till the temperature has fallen to about 200° Fahr. (93°·3 C.) The water which has been used for washing the crystals, is taken again for washing the first alum, as above.

Fig. 8.



At Valmunster this operation is carried on in vessels constructed as follows:—The wooden troughs are lined with lead in the ordinary way, but are closed by a lid in which are two openings; one of the openings receives the steam-pipe, and the other a wide leaden funnel. The sides of the funnel are perforated with small holes, 300 of which are inserted in every square foot of surface. In this funnel the alum flour is placed, and the steam injected through the pipe, in seeking to escape through the apertures in the funnel, dissolves the powder; the solution trickles to the bottom of the vessel at a temperature of 212° Fahr. (100° C.). At the termination of the process a small quantity of undissolved basic alum is left in the funnel, which is added to the concentrated liquor ready for precipitation, and is redissolved as before stated. During the time the flour is dissolving in the roching vessel, the crystallizers are being prepared, and the aluminous solution, of a density about 1·485 to 1·515, is run into them by appropriate means.

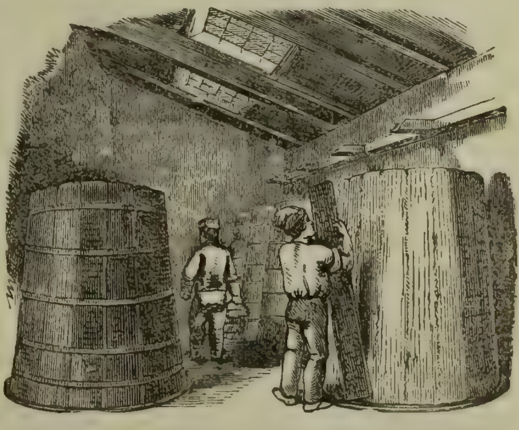
Fig. 9.



The crystallizers are large wooden casks, 5 to 8 feet high, 3 or 4 feet in diameter at the top, and tapering in a somewhat conical form towards the bottom. The staves of these casks are very strong, nicely adjusted, lined with sheet-lead, and held together by means of strong iron hoops, which are hammered on when required for use, and may be as easily removed.

Fig. 10 is a view of these casks arranged in the crystallizing shed; over each a spout is fixed to fill them with the liquor. Some of the casks are represented as on the point of being charged, while in others the crystallization is completed, and the staves are being taken off. When the casks are charged, they are covered up, each with its own lid. After remaining undisturbed for four or five days, according to the state of the weather, the hoops are loosened and the staves removed; the crust of alum then formed being sufficiently strong to resist the pressure of the interior liquor. In this state they are left for a fortnight, in order to allow the whole of the crystallizable salt to form. The workmen then pierce a few holes in the sides of the column with an axe, and the mother liquor in the interior flows into the gutters in the stone floor, which conduct it into an appropriate cistern, whence it is pumped up to dissolve fresh quantities of the pre-

Fig. 10.



pared alum flour. When the roching casks are dismantled, and the alum of the upper part removed, there is invariably found at the bottom a considerable quantity of white slime mixed with small octahedral crystals of alum. A quantity of this slime, well washed, gave the following centesimal composition:—

	Per Cent.
Sulphuric acid,	39·40
Alumina,	31·80
Potassa,	10·03
Moisture,	16·70
Insoluble matter,	2·07
	100·00

On examining the insoluble portion, it was found to contain—

	Per Cent.
Silica.	73·79
Alumina, with a trace of iron,	21·83
Lime,	3·49
Loss,	·89
	100·00

The mother liquor which remains after the separation of the alum, is composed of solutions of ferrous and ferric sulphates and chlorides, and magnesium and other alkaline sulphates; and when soap-boiler's waste has been used as the precipitating agent, it contains, in addition to the foregoing, sodium alum in moderate quantities; if bisulphate of potash, saturated with wood ashes, has been employed, the liquor will contain some sulphuric acid and other ingredients in small proportions. From a chemical analysis of the alum shale, or ore, in the first instance, a good idea can be formed of the principal bodies remaining in the mother liquor, and their utility for the formation of secondary products; for instance, if free acid should be detected in the lie, it may be employed to neutralize crude ammonium carbonate from the gas-works, to procure ammonium sulphate; or if much iron be present in the acid liquor, a further addition of borings of iron, or old iron, may be added, and in this way ferrous sulphate for manufacturing purposes formed. Should the mother liquor contain large quantities of the mixed chlorides of iron, it may be evaporated to dryness, and the dry mass heated to redness in a reverberatory furnace to drive off the hydrochloric acid, and thus ferric oxide obtained of a quality fit for use as a pigment.

Magnesium sulphate, Epsom salts, is also manufactured from the mother liquors of the ores.

The mass of alum from the crystallizing tub is cut into square blocks for market, when it will be found interiorly to consist of beautiful large octahedral crystals, similar to Fig. 11, which project from the sides and cover of the vessel.

For some purposes the alum is preferred in the form of a fine powder or flour; a portion is therefore prepared for the market in this state. Fig. 12 is a sketch of the machinery usually employed at the alum-works for this purpose. The alum, reduced to coarse fragments, is crushed beneath a pair of ponderous wheels or rollers of cast iron, one of which is rough or fluted on the rim, and the other perfectly smooth. These traverse in a circle, and the alum is constantly pushed into the path of their revolution by two vertical revolving blades, one of which sweeps it inward, and the other outward. The grooved roller crushes the larger fragments before they are subjected to the action of the smooth surface of the other. When one charge is thus reduced to powder, it is shovelled out by an attendant to make room for a new supply; and the powder is passed by hand into a hollow cylindrical sieve, shown at the right hand of the figure. The lower portion, or belly of the cylinder, which lies in a slightly inclined position, consists of fine wire gauze; the upper convexity is made of white iron. This is surrounded by wooden hoops, to which are attached brushes that pass into the interior of the cylinder. An oscillating motion is given to the latter, and that portion of the alum powder which has been reduced to a state of sufficient fineness is driven by the action of the brushes through the sieve, from which it falls in a beautiful white flour into a box below; the coarser particles passing onward to the other end of the cylinder, to be again subjected to the action of the crushing rollers.

Fig. 11.

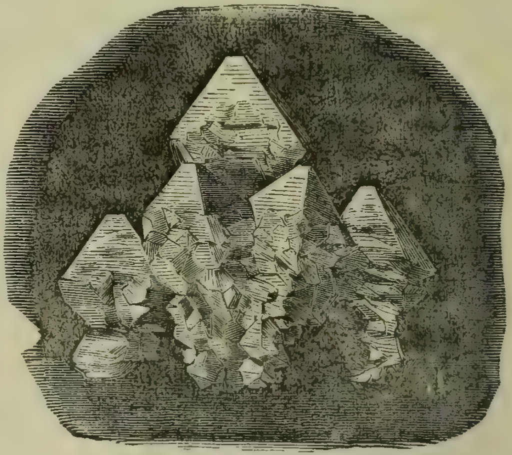
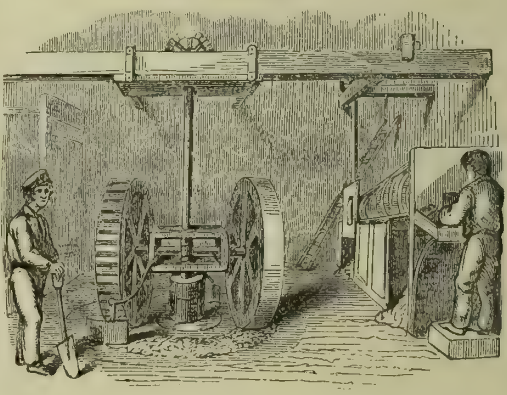


Fig. 12.



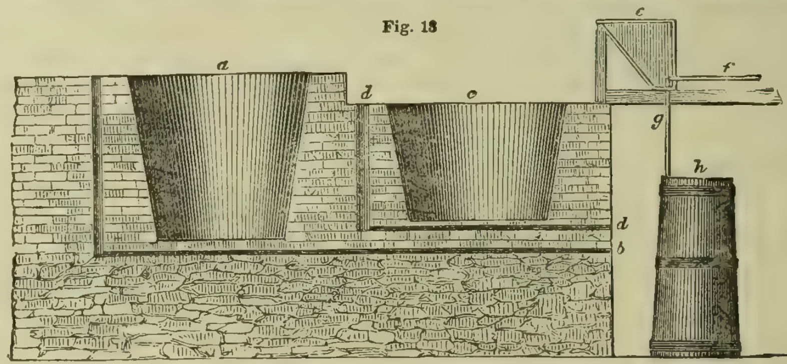
The most important changes which the manufacture of alum has undergone in the last ten years are the substitution of ordinary sulphuric acid for the sulphuric acid generated by the prolonged exposure to the air of iron pyrites. and the general substitution of ammonia for potash. The direct treatment of aluminiferous minerals with sulphuric acid was patented in 1845 by P. SPENCE, of Manchester, and was brought into practical use in 1847 by the firm of SPENCE & DICKSON. The importance of this step may be judged from the fact that while formerly 60 tons of the Berkshire oolitic schist were required to produce 1 ton of potash alum, the manufacture of 1 ton of ammonia alum by the new process does not take more than three-quarters of a ton of the same mineral. The schists used by Mr. SPENCE are found under the coal-beds of South Lancashire. This schist, which derives its black colour from the presence of carbonaceous matter, is piled up in heaps of from 4 to 5 feet in height, and calcined, as already described, at a heat bordering upon redness. The object of this process is to make the alumina more readily soluble in sulphuric acid. If the temperature is too high, a partial vitrification (fritting) results, and the alumina is rendered almost insoluble in the acid. The calcination lasts ten days, a certain quantity of fresh schist being added daily. When the operation has been well conducted, the residue is soft and porous, and of a light brick red. It is placed in covered vessels, each capable of holding 20 tons, and digested for thirty-six to forty-eight hours with sulphuric acid of spec. grav. 1·35. The mixture is kept at the heat of 230° Fahr. (110° C.), by a fire beneath, and by driving in the vapour of an adjoining boiler containing gas-liquor. This simultaneous treatment gives excellent results, provided that the acid is always kept in excess. The ammoniacal salts pass into the digesters, and are there decomposed by the acid. The excess of ammonia is afterwards set at liberty by the addition of a certain quantity of lime. The ammoniacal liquor flows into cisterns, and is stirred continually while cooling, in order to determine the formation of small crystals. These crystals are subsequently dried, and then washed with the mother liquor that drops from the blocks of alum. Not a trace of iron is found in these crystals, though the mother liquor contains it in abundance in the state of sulphate. This result is commonly obtained by means of rapidly redissolving and recrystallizing the alum. SPENCE arrives at the same result by means of steam, without addition of water as a solvent. The crystals are thrown into a hopper, at the bottom of which they come in contact with a current of steam, which rapidly dissolves them. The crystals and the steam are in such proportions that all the crystals are dissolved when all the steam is condensed: 4 tons of crystals are thus dissolved in thirty to forty-five minutes. The solution flows into a leaden tank, where it stands for three hours, depositing a certain quantity of matter insoluble both in acid and water—probably basic sulphate of alumina. The liquor is thence run into cylinders, the bottoms of which are made of Berkshire flagstone, and which are 2 yards in diameter, with movable sides. After standing from five to eight days, the sides are removed, and a cylindrical mass of crystallized alum is found. After standing again for eight days, a hole in the bottom of the cylinder is opened, and a quantity of liquid escapes. The mass is generally 18 inches thick at the bottom, and 1 foot in the sides, and contains 3 tons of marketable alum. The liquid which escapes contains another ton. The blocks of alum obtained by this process often present a faint rose shade, which a hasty observer might attribute to metallic impurities. This tint is due to the presence of organic matter, probably a trace of aniline, derived from the gas-liquor.

The substitution of ammonia for potash is not peculiar to those establishments which make direct use of sulphuric acid. In consequence of the rise in the price of potassic salts, ammonia has been introduced into the manufactories which still work on the old method, not only in England and in France, but in Germany. In 1851 the great Bonner Works made exclusively potash alum. Now, with the exception of some 300 tons, its entire yearly production is ammonia alum. Many samples sold as potash alum contain a proportion of ammonia.

PRODUCTION OF ALUM FROM ROCKS CONTAINING ALUMINA.—Alum has been produced from various rocks of which alumina forms a constituent, by a process similar to that which naturally gives rise to this body in volcanic districts. The operation is confined to one or two isolated works on the Continent, and those are conducted in juxtaposition with metallurgic operations where sulphurous acid is in abundance. At Lintz, on the Rhine, where there is a spelter work and plenty of zincblende, zinc sulphide, the sulphurous acid evolved during the roasting of the ore is conducted over the aluminous mineral moistened with water. Basalt and copper slate are the materials employed, and when these are exposed to the action of the gas and sufficient moisture and air, decomposition ensues, aluminium sulphate, with sulphates of iron and copper, are formed, which are separated from the insoluble residue by steeping with water, and the subsequent treatment for obtaining the alum is on the same principle as those methods which have been already described. In such operations there is always a quantity of sodium alum produced, on account of the presence of this alkali in the basaltic mineral. The sodium alum is formed from the commencement, and the amount corresponds of course with that of the soda in the mineral, which in many basalt rocks is from 5 to 6 per cent.

ALUM FROM CLAY. — CHAPTAL and ALBAN, in France, devised a different process for the preparation of alum from clay. Clay consists of basic aluminium silicate, free alumina, and by the action of sulphuric acid aluminium sulphate is formed with separation of silicic acid. Pipe-clay answers the purpose best; but that the acid may more readily penetrate the mass, the clay is submitted to a previous calcination to increase its porosity, and more fully oxidize the iron which it may contain. Fresh clay, when employed, requires a considerably longer time than when it is calcined and pulverized previously to the addition of the acid; if it be found requisite, the ground material is sifted: 45 per cent. of the weight of the clay of sulphuric acid, of 45° B., is poured upon it in a cistern which is heated, by the surplus heat from the calcining furnace, to about 158° Fahr. (70° C.). Decomposition ensues, and the mass assumes greater consistence from the liberation of silicic acid; in this state the contents of the cistern are removed to the open air, where they are allowed to remain for a space of some months, to allow of the complete disintegration of the clay by the acid. The mass is afterwards lixiviated and the aluminium sulphate treated as in ordinary cases. Clay with as little iron and lime as possible should be selected. Some manufacturers employ large shallow troughs, lined with lead and heated from below by flues, for the purpose of mixing the prepared clay with sulphuric acid, in which it is frequently turned over until the acid has combined with its alumina. In this part of the operation an improvement has been lately effected, which consists of distributing the clay upon a shallow circular trough, and permitting the proper quantity of acid to flow in several small jets from a cistern placed above, whilst an agitator, worked by machinery, mixes the the clay and acid thoroughly. In this way a speedy combination is effected. After the termination of the action of the acid the contents of the cistern are removed to the stone vat, *a*, Fig. 13, where they are treated with successive quantities of water, to extract the aluminium sulphate. Each lie is siphoned off into the pipes, *b b*, which convey it to the evaporating pans, to be boiled down to the proper strength for precipitating with the alkaline salt. When this point is attained the liquor is pumped up into the cistern, *c*, which is similar to *a*, already described, and called the precipitating vat; here the appropriate quantity of potassium sulphate is added. On agitating the solution the "alum powder" precipitates; this is allowed to subside, and the mother liquor is drawn off to the pipes, *d d*, by a syphon. If the mother liquor be not very impure it is employed for a subsequent precipitation. The precipitated alum is washed in the cistern, *c*, with successive small portions of water, each liquor being drawn off repeatedly in the same way as the mother liquor.

Fig. 13



When the powder is purified by repeated washings, it is ladled out into the funnel-shaped vessel, *e*, where it is very economically dissolved, by injecting steam upon it through the pipe, *f*, and the saturated solution of alum descends to the crystallizing frame, *h*, through the pipe, *g*.

The evaporation of the various liquors is conducted in boilers lined with lead, by means of convoluted steam pipes placed in the liquid. This plan of concentration of the liquid is found to be best adapted for such liquors, as well as being cheaper.

Taylor, of Bristol, manufactured alum from pipeclay by calcining it in the usual way, and then treating it with its own weight of sulphuric acid, of specific gravity 1·200, in a large tub, upon the bottom of which a steam-pipe is coiled for the purpose of heating the mixture to about 200° or 212° Fahr. (93°·3 to 100° C.); furnace clinkers and pieces of pottery, or other matters, are also strewed upon it to facilitate the filtration of the solution of aluminium sulphate. After the mixture of clay and acid has been heated for twelve hours, the solution is drawn off through a pipe at the bottom of the tube to the precipitating vats at a density of 1·300.

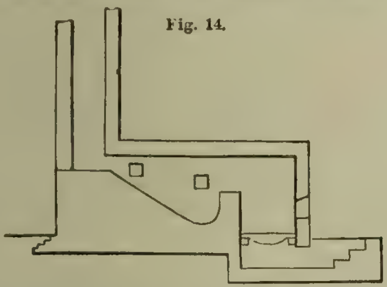
Pochin, of Manchester, first prepared alum cake from china clay. This product is much esteemed on account of the large amount of aluminium sulphate it contains. A clay is chosen which is as free from iron as possible, and heated gently in a furnace with access of air, in order to remove the water and render the clay more soluble in acids. By losing its water the clay becomes very porous, and takes up the acid with great avidity by capillarity. The gently ignited and powdered clay is then gradually added to sulphuric acid, of specific gravity 1·52, in leaden pans; here the mass thickens, heats violently, and boils; it is then transferred to iron tanks, where it ultimately solidifies. The porous mass is perfectly dry, though still retaining a large amount of combined water. It also contains all the silica originally in the clay, but in an extremely fine state of division. If it is desired to convert the alum cake into alum, it is lixiviated with the washings from alum flour; and the solution, after standing to become clear, treated with potassium bisulphate, or ammonium sulphate from gas liquor, in the usual way.

From Felspar.—This mineral, which is a double silicate of alumina and potassa—$AlKSi_3O_8$, or

$AlKSiO_4,2SiO_2$—is decomposed by potassium sulphate in a reverberatory furnace, and then fused with carbonate of potash to a glass; on treating this with boiling water decomposition follows, a soluble silicate of potash dissolves, while an insoluble double silicate remains. The insoluble portion, when treated with boiling sulphuric acid, is decomposed into alum, and silica separates. The alum is dissolved out by water, and the solution evaporated for crystallization; the soluble alkaline silicate may be turned to account by combining the silica with lime.

Turner was the first to carry out the proposition of Sprengel, of converting felspar into alum. A patent was granted to him in 1842 for his process, which he describes in his specification as follows:—If desirous of making potash alum, the best substance to operate upon is a potash felspar. This felspar is ground in a common edgestone mill, till the powder is like fine sand, a process which is much assisted by heating it to redness, and then plunging it in cold water; it is afterwards mixed with its own weight of sulphate of potash, and placed in the upper part of the inclined bed of a reverberatory furnace, similar to the annexed Fig. 14—known in the potteries as a *frit-furnace*—previously brought to a red heat. When the glass produced by the fusion of the powdered mineral and the alkaline sulphate has been observed to flow down to the bed of the furnace, there is added gradually, at the lower end of the furnace, as much carbonate of potash as was previously used of sulphate. This operation of adding proportionate quantities of carbonate of potash to the molten mass as it flows down into the lower part of the furnace, is continued till the "sack" of the furnace is quite full, the mineral and sulphate being introduced at the upper end: the glass is then fit for the next operation.

Fig. 14.



The compound might be prepared in a furnace with a flat bottom, from which it can be separated with greater facility; in this case, however, no carbonate should be used till the whole of the sulphate has been seen to be decomposed, after which it is to be introduced, as in the preceding instance, and fused with the mass. On boiling the glass produced in this manner with water, the same quantity of potash as was added to the felspar, and two-thirds of the silica contained in the mineral, are dissolved, while the remaining one-third of silica, and the alumina, and an equal quantity of potash as the felspar originally contained, are left in the form of a light porous substance, which is carefully separated from the solution, and washed well with water to withdraw potassium silicate; next, the porous precipitate is put into a large leaden cistern or boiler, and acted upon with boiling sulphuric acid, of specific gravity 1·20, which will contain sufficient water for the solution and crystallization of the alum formed by the decomposition of the mass. As a general rule, as much acid should be added in the diluted state as will contain 160 lbs. of dry acid to every 285 lbs. of felspar employed. The boiling liquor, after the sediment has subsided, is drawn into coolers, such as are generally used for crystallizing alum; here about four-fifths of the alum contained in the liquor will separate into crystals. From this mother liquor the residual alum is obtained by evaporating it to dryness; by this means the silica present in the solution is rendered insoluble, and the dry mass is acted upon either with water or a further quantity of mother liquor, and the solution evaporated to the crystallizing point as before. When ammonium or sodium salts are used in the above process, ammonium and sodium alums are produced.

With the exception of the high temperature required to decompose the felspar, Turner's process is very successful, but this was found to be a serious drawback when working on the large scale.

Alum may likewise be obtained by treating a mixture of two parts of felspar and three of fluorspar with sulphuric acid at a low red heat, until vapours of hydro-fluosilicic acid cease to be evolved. The decomposition of the fluorspar by the sulphuric acid causes the liberation of hydrofluoric acid, and this in turn decomposes the silicates, combining with their silicic acid to form the evolved hydro-fluosilicic acid. Sulphate of lime is formed in the first stage of the process; but this is subsequently decomposed, and potassium and aluminium sulphates formed.

The mass is lixiviated with water, and after the separation of some sulphate of lime, the solution is evaporated, and on cooling it deposits an abundant crop of nearly pure alum crystals.

From Cryolite or Greenland Spar.—This mineral has the composition:—

Aluminium,	13·0
Fluorine,	54·5
Sodium,	32·5
	100·0

and is represented by the formula, $Al_2Na_3F_6$. It has of late years been much used for the production of soda and alum. Its decomposition is effected in the dry way by igniting it with calcium carbonate in the proportion of 6 equivalents of Ca_2CO_3 to 1 of of cryolite, when

$$\overset{\text{Cyrolite.}}{Al_2Na_3F_6} + 6Ca_2CO_3 = \overset{\text{Calcium Fluoride.}}{6CaF} + \overset{\text{Sodium Aluminate.}}{Al_2Na_3O_3}$$

The sodium aluminate is extracted with water decanted from the heavy calcium fluoride. Carbonic acid gas is then passed into the solution, when sodium carbonate is formed, and gelatinous alumina is precipitated. This precipitate is collected, dissolved in dilute sulphuric acid, and evaporated to obtain aluminium sulphate, or treated with an ammonium or potassium salt to convert it into alum:

100 parts by weight of cryolite yield 305 parts of alum.

Cryolite is also decomposed by boiling it, after having pulverized it very finely, with lime and water in a leaden pan. The result of the interchange of constituents is the same as that given above, aluminate of soda and fluoride of calcium being produced. When the heavy calcium salt has settled down the clear liquor is decanted and the sediments washed, the first washings being added to the original liquor, and the second and third washings used instead of pure water at a subsequent stage. The alumina is then precipitated by adding finely pulverizd cryolite in excess, thus:—

$$\underset{\text{Sodium Aluminate.}}{Al_2Na_3O_3} + \underset{\text{Cryolite.}}{Al_2Na_3F_6} = \underset{\text{Alumina.}}{2Al_2Na_3F_6} + \underset{\text{Sodium Fluoride.}}{6NaF.}$$

The gelatinous alumina is allowed to settle, and treated by any of the methods previously described.

SPENCE of Manchester has recently patented a process for the manufacture of alum from Rodonda phosphates, a mineral from the West Indies containing alumina with phosphate of iron in variable quantity.

The treatment for the aforesaid purposes of the said minerals may be varied in details, but the following is a description:—The raw mineral is calcined in kilns (similar to those used for lime) by mixing it with coal or coke and exposing it to a red heat, or else it is ground sufficiently fine to pass through a sieve of twenty meshes to the inch. The former plan is, however, preferable, as it facilitates the solution of the mineral substance, and renders a portion of the iron insoluble by oxidation. The mineral having been prepared by these or similar means, is then placed in leaden vessels, and an equal weight of sulphuric acid of spec. grav. 1·6 added to it, if it contains 20 per cent. of alumina, but only three-fifths of its weight if it contain 12 per cent., and in similar proportions for other degrees of richness. Heat is then applied by blowing steam into the vessel containing the mixture. The mineral dissolves and the specific gravity rises. This is cautiously reduced by addition of water or weak liquors from subsequent parts of the process, the whole being kept constantly boiling until all is dissolved except the insoluble sediment, and the strength of the liquor becomes 90 Twaddle, or 1·45 spec. grav. This liquor is next passed into a close leaden vessel, and vapour distilled into it containing ammonia obtained from gas ammoniacal liquor, subjected to boiling either by fire or steam injected into it. The quantity of gas liquor I used being from 600 to 900 gallons to each ton of the mineral, according to its richness. When all the ammonia has been distilled into the mineral liquor it is allowed to settle for a few hours, and all the clear solution (now at a strength or spec. grav. of 1·4 or 80 Twaddle) is run off into lead coolers, where the alum crystallizes out in the usual way. The liquor remains in these coolers for some days, with frequent stirring, in order to obtain all the alum possible. SPENCE finds that when the mineral contains 20 per cent. of alumina, that he obtains about 1½ tons of alum from 1 ton of the ore.

The mother liquors having deposited all the alum that can be obtained, is now chiefly a solution of phosphoric acid with a small quantity of aluminium and iron sulphate, and ammonium sulphate or phosphate of ammonia. This liquid may be used directly as a fertilizing agent, but is usually mixed with dry sawdust or other absorbing agent, in just sufficient quantity to absorb all the liquor. It is then dried at a low heat, so as not to char the sawdust; and when dry it forms an artificial manure containing phosphoric acid and ammonia, in such quantities and condition as to make it a valuable fertilizer. Instead of ammonia gas liquor used with the mineral solution to produce alum, salts of potash may be used either alone or in combination with ammonia; of the former, the chloride of potassium of commerce, or preferably sulphate of potash, as although chloride of potassium will yield a sufficient product of alum, the fertilizer would from its use have a tendency to deliquesce, but sulphate of potash will not have that effect.

WILSON, of Glasgow, patented a process for the manufacture of alum, the chief novelty of which consisted in heating the liquids for the digesting the shale, and in applying the mother liquors after precipitating or separating the alum, so as to make the sulphuric acid, either free or in combination with other bodies, available in subsequent operations.

The mixture of sulphuric acid and water is warmed in a separate vessel, and then run into the digesting tank containing the calcined shale, at a temperature between 150° and 200° Fahr. (65°·5 to 93°·3 C.), and the heat maintained at the proper degree by conducting the waste heat from the furnace of the heating vessel below, through flues under and around the digesters.

To prevent the loss of sulphuric acid, the ordinary method is varied in the following manner:—The strong mother liquors, left over after depositing the alum formed from the combination of the aluminium sulphate with the ammonium sulphate, are not used again to dilute the acid, but are employed with fresh ammoniacal liquor from the gas works or elsewhere, to form sulphate of ammonia. The decomposition of the portion of alum which the mother liquor held in solution is guarded against by adding the ammoniacal liquor in such quantities, that a slight portion of the acid in the liquor is uncombined. A few trials enable the operator to judge, by means of test papers, the proper point at which the neutralizing should be suspended.

When the solution of the mixture of ammonium sulphate and alum, after filtration or reposing to allow impurities to deposit, is sufficiently concentrated by evaporation, it is run in among the solution of aluminum sulphate from the digesters, and the alum which it contains is deposited with that of the fresh liquor.

RICHARDSON, in 1850, sealed a patent for further improvements in the manufacture of alum, the leading parts of which are as follow:—In lixiviating the calcined shale for the purpose of obtaining the raw alum liquor, a series of pits, such as is seen in the annexed figure, is employed. Fig. 15 shows the manner of effecting the solution of the aluminium sulphate. B^1 B^2 B^3, &c., are a series of pits, furnished with pipes, A^1 A^2 A^3, &c., for the purpose of conveying mother liquor from one to another, the pipes being stopped with taps or cocks, as seen in the figure. Water is run from the service tank, D, through the pipe, C, into the pit, B^6, till it flows over through the pipe, A^6, and passes through the pipe, E E, till it enters B^1, through which it rises till the pit is filled, exhausting the contents of the soluble ingredients in its ascent. When the liquor has stood for some days, a fresh supply of water is continued as before in B^6, by which the liquor in B^1 is forced over through A^1, the plug being removed into the pit, B^2, containing fresh calcined shale; the liquor ascends through the shale in this pit as in B^1, and when it has remained two or three days in contact with it, a fresh supply of water is allowed to flow into B^6, which forces the liquid contents of B^2 into the third tank, and the treatment repeated as long as the workmen find it necessary to bring the liquor to 28° Twaddle, or such higher strength as is required; and when the proper degree of saturation is attained, the solution is drawn off by the stopcock, F. As soon as the shale in any of the pits is found to be exhausted, it is removed, and a fresh supply introduced, and the lixiviation proceeded with as before.

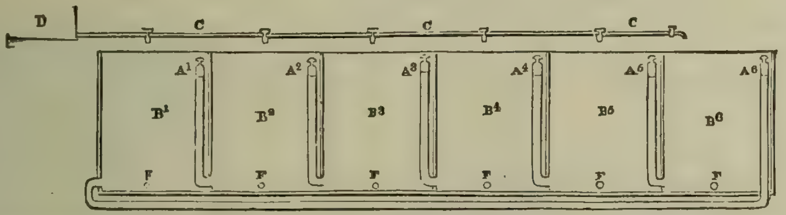
Of course, as the operation goes on week after week, it will become necessary to commence the supply of water from the service tank, D, to the different pits in succession, which may be done as above described, or by allowing it to run at once down the pipes, A A A, from the respective taps in the pipe, C. By these arrangements the labour of pumping the liquor from one pit to the other will be saved, the process generally rendered more convenient, and the result will be a more perfect exhaustion of the shale.

PRODUCE.—The great variation in the character and richness of the ores does not admit of even a proximate relation being established between the quantities employed and the amounts of alum produced in different works. At Valmunster, from 17,300,000 lbs. weight of alum shale, 400,000 lbs. of alum, or 2·3 per cent., are obtained, for the production of which 100,000 lbs. of sulphate of potassa are required, and 1,400,000 lbs. of coal consumed.

The slate at Liége yields 2 per. cent of alum, and that from other localities only from 1 to ½ per cent.

IMPURITIES.—Alum always contains a little iron; that from Liége contains 0·02 per cent.; that from Gavelle, near Paris, 0·08 per cent.; that from Aveyron, 0·11 per cent.; and English alum about 0·12 per cent. This amount of iron is sufficient to impair the delicate colours used in calico-printing; it can, however, be removed by recrystallization, or as prussian blue, by means of potassium ferrocyanide (K_4FeCy_6). The Roman alums—a name given to all varieties of alum imported from Italy—are sufficiently pure for immediate use, and are highly prized on account of the minuteness of the quantity of iron which they contain.

Fig. 15.



Roman alum commonly consists of small disconnected crystals, covered externally with a kind of reddish mud; on the alum being dissolved in water none of this coating is acted upon, and the quantity of iron alum present in the solution does not exceed 0·005 per cent. Alum of this description produces a blue precipitate with potassium ferrocyanide only after standing for several hours, while ordinary alum affords a precipitate in a few minutes. Roman alum is generally crystallized in the form of octahedrons, though cubical crystals are occasionally found. Its reactions differ from those of ordinary alum in many respects.

CHEMISTRY OF ALUM.—Potassium alum requires about 18 parts by weight of cold, and less than 1 part of boiling water to dissolve it, and crystallizes very readily in large regular octahedrons, of which the apices are always more or less cut off. Its taste is sweetish, and very astringent. It is an acid salt, reddens vegetable blues, and dissolves metals with evolution of hydrogen; in the air it changes very slightly. Its water of crystallization amounts to 45·5 per cent. of its weight, or 12 atoms; thus it loses its water of crystallization with great facility at 197°·6 Fahr. (92° C.). The fused salt in losing this water becomes viscid and intumesces, leaving calcined or burnt alum, which is sometimes used as a caustic which dissolves in water, although but slowly.

The octahedral crystals of potassium alum consist of sulphuric acid, aluminium, potassium, and water. and have the formula $AlK(SO_4)_2 12H_2O$.

When octahedral alum is digested with hydrated alumina, and the solution allowed to evaporate spontaneously by exposure, cubical crystals are formed with a simultaneous separation of a basic salt of alumina; the crystals have an acid reaction, and the same properties as ordinary octahedral alum.

LOEWEL prepared pure potassium and ammonium alums, crystallized under the ordinary octahedral system, and obtained cubic crystals of potassium alum by dissolving the octahedral crystals in three or four times their weight of water, heated from 72° to 81°

Fahr. (22°·2 to 27°·2 C.), and adding an aqueous solution of potassium hydrate in alcohol in successive small portions, till the subsalt of alumina, thrown down by each addition, was no longer dissolved upon the agitation of the liquid. The form assumed by the salt after adding a quantity of potassium equal to about one and a half equivalents aluminium (that is, on taking from the aluminium sulphate contained in the alum nearly half its acid), was that of truncated and cubical octahedrons; but on the further addition of alkali, cubes were formed on spontaneous evaporation of the liquid.

Cubical ammonium alum he procured by dissolving the pure octahedral salt in three to four times its weight of water at 113° Fahr. (45° C.), and adding ammonia till the small quantity of subsalt ceased to dissolve in the solution.

When some of the solutions thus prepared had given a certain quantity of cubic crystals the solution became cloudy, and deposited a gelatinous tribasic aluminium sulphate ($Al_2O_2(SO_4) + 9H_2O$).

The potassium and ammonium cubic alums resist the action of air dried by sulphuric acid in a bell-jar for weeks without efflorescing. Loewel suggests that it would be more correct to state that no efflorescence takes place. He placed crystals of pure alum under bell-jars, in which the air was dried by sulphuric acid; at first the crystals lost some thousandths of their weight of interposed water, but afterwards remained for several months, even for a whole year, at a temperature rising to 77° Fahr. (25°·0 C.).

According to De Hauer a crystal of cubic alum when placed in a solution of alum rendered basic by addition of an alkali, continues to grow, preserving at the same time its cubical form; and if its faces be cut so as to make it an octahedron before placing it in such a solution, the cubical shape is in a short time restored. The opposite phenomenon is observed when an octahedral crystal, cut into a cube, is immersed in a solution of ordinary alum.

When the cubical crystals of Roman alum are dissolved in water, at a temperature ranging between 96° and 104° Fahr. (35°·5 to 40° C.), and the solution set aside to crystallize by spontaneous evaporation, the alum is again produced in cubes. At a higher temperature the solution becomes turbid from the separation of basic alum, and the clear liquor deposits alum in octahedral crystals.

The solubility of potassium alum is, according to Poggiale, as follows:—

Alum melts at 197°·6 Fahr. (92° C.).

		Fahr.			
100 parts	of water at	32°,	dissolve	3·29	parts of alum.
"	"	50	"	0·52	"
"	"	86	"	22·00	"
"	"	140	"	31·00	"
"	"	158	"	90·00	"
"	"	112	"	357·00	"

At a white heat all the sulphuric acid and the water of crystallization pass off as sulphurous acid, oxygen, and steam, leaving a mixture of alumina and potassium sulphate. At a still higher temperature aluminate of potassium is obtained. Potassium alum, on being heated to redness with sugar out of contact with air, is converted into alumina, carbon, and potassium sulphide, in a fine state of division, and constitutes the pyrophorus of Homberg, which ignites spontaneously on exposure to air.

Alum, when heated with alkaline chlorides, liberates hydrochloric acid; again, if a concentrated solution of this salt is boiled with sodium or potassium chlorides, the same acid is given off, and a sparingly soluble basic alum precipitated. Richter states that a solution containing alum, chloride of sodium, and nitrate of soda, is a solvent for gold.

When alum is dissolved in twenty parts of water, and ammonia dropped slowly into the solution till the liquid is nearly saturated, a bulky white precipitate appears, which, when thoroughly washed with distilled water, is pure alumina. If dried and weighed, it will be found to be 10·82 per cent. of the weight of the alum taken. If this precipitate while moist be dissolved in dilute sulphuric acid, it constitutes, when as neutral as possible, the normal aluminium sulphate of alumina ($Al_2(SO_4)_3$), which requires only 2 parts of cold water for solution. If this solution be now decomposed by pouring into it liquid ammonia, there appears an insoluble white powder, the tribasic sulphate or basic alum. It contains three times as much earth as the neutral sulphate. However, by adding a strong solution of potassium sulphate to that of the neutral sulphate, a white powder will fall, which is true alum. When recently-precipitated alumina is boiled in a solution of alum, a portion of the earth enters into combination with the salt, constituting the insoluble compound which falls as a white amorphous powder: the same combination occurs if a boiling solution of alum be decomposed by potassium hydrate.

Ammonium alum, ammonio-aluminic sulphate ($Al(NH_4)SO_4,12H_2O$) behaves in all respects as does potassium alum, except that it is more soluble in water, 100 parts dissolving 5·22 parts of ammonium alum at 32° Fahr. (0° C.), and 421·9 parts at 212° Fahr. (100° C.). When heated to redness it loses both its sulphuric acid and ammonia, and becomes alumina. Addition of ammonia to a boiling solution of ammonium alum gives rise to a basic alum as in the case of potassium alum.

Argento-aluminic sulphate, silver alum, has been prepared by Church by heating silver and aluminium sulphates, together with water in an oil bath. This salt crystallizes in octahedra, and is decomposed by water. Its formula is $AlAg(SO_4)_2,12H_2O$.

Sodio-aluminic sulphate, $AlNa(SO_4)_2 12H_2O$, sodium alum, crystallizes in large octahedras, but with great difficulty. But for this cause it would be largely used on account of its great solubility. It is much more soluble than potassium alum; 10 parts of water dissolve 11 parts of this alum at ordinary temperature. In all other characteristics it resembles potassium alum.

The relative solubilities of the three common alums at 60° Fahr. (15°·5 C.) in 100 parts of water are—ammonium alum, 9·37; potassium alum, 14·79; sodium alum, 327·6.

SULPHATE OF ALUMINA. — *Aluminium sulphate*, $Al_2(SO_4)_3 + 18H_2O$.—This substance has of late years been very largely manufactured, and sold under the name of concentrated alum. It occurs in commerce as four-sided plates about an inch in thickness, which are white and partially translucent, dissolve perfectly in water, exhibit no trace of crystallization, and possess the peculiar taste of alum in a more marked degree than even alum itself. The commercial salt is entirely free from iron, and can be cut with a knife. It is very soluble in water, and has an acid reaction. Heated to redness, it is decomposed, leaving pure alumina. The process for its preparation consists in treating clay, cryolite, bauxite, &c., with sulphuric acid in the manner before described; and differs only in adding no potassium sulphate to the solution of aluminium sulphate, and in precipitating any iron that may be present by adding potassium ferrocyanide, evaporating to the consistence at which the mass will solidify when cold, and then pouring it into the "melting vessel." MOHR found this substance, which is improperly called alum, to be perfectly free from iron, and to contain—

Alumina,........................	13·91	per. cent.
Sulphuric acid,....................	36·24	"
Water.........................	49·60	"
Potassium sulphate,...............	1·50	"

The latter ingredient is due to the small portion of potassa naturally existing in all clays. The preceding composition corresponds exactly with the combinations of

7·1 per. cent. of ordinary potassium alum, and
92·9 " of neutral aluminium sulphate.
The formula of which is $Al_2(SO_4)_3 + 18H_2O$.

WIESMANN'S process for the preparation of pure aluminium sulphate consists in agitating the crude solution of sulphate of alumina in a large wooden vessel with potassium ferrocyanide.

The vessel wherein the mixture is made is similar to A, in Fig. 16. After allowing the bulk of the precipitated prussian blue to subside, the supernatant liquor is run off into the wooden vessels, B B B, where it remains until perfectly clear and free from precipitate, after which the clear liquor is treated as has been already described.

The precipitated prussian blue is repeatedly washed with cold water to separate the whole of the aluminium sulphate, and the solutions are drawn off into some of the vessels, B, for the above object.

The prussian blue is now treated with a lie of caustic soda to separate the iron, and thus the same precipitant serves for a long period with very little loss.

The refuse matter which remains contains some sulphuric acid, and resists the solvent action of water.

Two samples of this residuary matter gave the annexed results:—

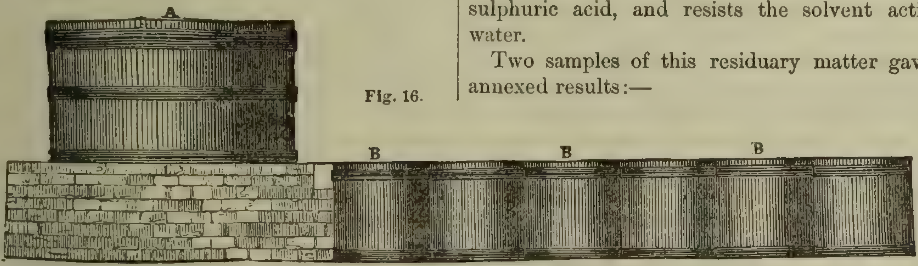


Fig. 16.

Silica,................................	41 85 ..	39·05
Alumina, with traces of sesquioxide of iron,	18·40 ..	25·55
Sulphuric acid,.........................	4·45 ..	8·47
Sulphate of lime,.......................	4·01 ..	traces
Water,................................	29·53 ..	27·50
Loss,.................................	1·76 ..	—
	100·00	100·57

The composition of aluminium sulphate, as met with in commerce, varies very greatly. In four samples analyzed by VARRENTRAPP, he found:—

		Theoretic amount of Sulphuric Acid.
1.		
Alumina,..................	15·3	
Sulphuric acid,.............	38·0...........	35·8
2.		
Alumina,..................	12·5	
Sulphuric acid,.............	30·6...........	29·2
3.		
Alumina,..................	15·1	
Sulphuric acid,.............	38·0...........	43·3
4.		
Alumina,..................	13·0	
Sulphuric acid,.............	34·0...........	30·5

And also that the quantity of water varies even in the same cake.

FLECK found similar differences. Below are given his results for three samples:—

	I.	II.	III.
Aluminium sulphate,............	47·35	50·80	51·63
Sodium sulphate................	4·35	1·24	0·77
Free sulphuric acid,............	0·73	0·27	—
Water,......................	47·37	47·47	46·94
	99·80	99·78	99·34

In prospect of aluminium sulphate being largely used for the clarification of sewage, Sidney W. Rich devised a process of manufacture by which he states that this salt may be profitably manufactured on the large scale to sell at 30*s*. per ton. He makes use of the aluminous shale of Guisborough; after burning, and whilst still hot, he places it in a brick tower 18 feet high. By withdrawing the burnt material from the bottom, and continually renewing the heap of burning shale at the top of the tower, a continuous passing of the material down the tower is effected. Whilst this is in progress sulphurous acid gas is introduced at the bottom of the tower from a pyrites burner, mixed with air and steam. Owing to the high temperature, and to the joint presence of the several reagents, the whole of the sulphurous acid gas is converted into sulphuric acid, and in consequence masses of the burnt shale come down, in large part converted into soluble aluminium sulphate. The method of lixiviating employed involves the treatment of the hot crude sulphate with water in tubs which run on an inclined tram, and work on the principle of the lixiviating vats for alkali. The crude sulphate being lixiviated while it is at a high temperature, the liquor becomes boiling hot, and is drawn off in a highly concentrated state; so that very little expense is incurred for fuel and evaporating pans.

Pure aluminium sulphate crystallizes, although with difficulty, in thin pearly flakes, and takes up at the same time 18 molecules of water. It is soluble in half its weight of cold water, but is scarcely at all soluble in alcohol. When heated it parts with its water of crystallization, and leaves a white porous mass, which is anhydrous aluminium sulphate ($Al_2(SO_4)_3$). This modification dissolves very slowly in water.

USES.—Alum is largely employed in the arts, chiefly in consequence of the affinity which alumina has for colouring and other vegetable matters; for gelatine, and a number of like bodies. The fibre of cotton, wool, &c., has such an affinity for alumina or a basic salt of aluminium, that when immersed in a solution of alum a basic salt is formed, which adheres to it so firmly that it cannot be removed by washing.

This basing with aluminium salts enables the cloth to unite with larger quantities of the colouring matter, and retain it with greater persistency. Some precautions are to be observed in its use in the hands of the cloth printer, which will not here be entered into, as they form a part of the subject to be treated of under CALICO-PRINTING.

Alum is used in preparing white leather, technically "tawing;" to clarify water, by the combinations which it forms with the foreign matters present, and also in the preparation of bookbinder's paste. A large quantity of alum is taken medicinally, as a topical and internal remedy in various diseases. Alum mixed with gypsum (calcium sulphate) forms the chief ingredient with which the outer chambers of MILNER'S fire-resisting safes are lined, so as to protect the interior from being injured. This it does from two causes: firstly, the large quantity of water it contains, which helps to moisten the inner chamber when the box is heated, and so prevents the contents from being consumed; and secondly, from the non-conducting power of the mixture after the water is expelled. The great success which has attended the application is the best testimony to its efficiency.

ALUMINA.—*Aluminium Oxide. Alumine*, French; *alumium oxyd*, *alaunerde*, *thonerde*, German. Formula, Al_2O_3.—This body is assumed to be a sesquioxide, from its being isomorphous with ferric oxide (Fe_2O_3).

The utility of alum in calico-printing rests solely upon its being a soluble modification of this earth. Alumina is extensively used, united with silica, in the manufacture of all kinds of earthen and porcelain ware; in the manufacture of crucibles, mortars, and cements. It is particularly employed, almost pure, for the manufacture of *glass pots*, the refractory power of the earth being so great as to permit the fusion of the *frit*, itself remaining unaltered either by the intense heat or by the molten substances.

Alumina occurs in the earth's crust, but rarely in a pure state. When so found it constitutes the mineral corundum, varieties of which, distinguished by their colour, are the sapphire, the ruby, oriental topaz, amethyst, &c.

Alumina constitutes a large proportion of all the slaty and shaly rocks. It is the main ingredient also of pipe-clay and argillaceous soils, which increase in tenacity in proportion to the quantity of alumina they contain.

Though it exists so largely in the soil, it contributes but little in a direct manner to the nourishment of plants, as the ash they leave contains, in general, a very small quantity of alumina.

Emery, much used for polishing and grinding, is an opaque variety of corundum. The Bessemer wheel for grinding steel without loss of temper is composed of emery bound together by RANSOME'S silicate of lime. It thus forms a cutting stone capable of grinding chisels from old files, at a cost of less than 5 per cent. of the stone in comparison with the metal.

Preparation.—Alumina may be precipitated by an alkali from any of its solutions as a bulky, white, amorphous powder, which, when collected, well washed, and dried, is pure. It is a white, tasteless, earthy substance, adheres to the tongue, has a specific gravity of 2·00, and is insoluble in water, but dissolves easily in caustic potassa and soda, and in most acids, at least when newly thrown down. When heated to redness, however, it becomes hard and dense, as in burned clay and firebricks, gives out sparks when struck with steel, and can hardly be scratched with a file. It is then almost insoluble, even in the strongest acids. ROSE states that the specific gravity of alumina increases after long ignition. After exposure for some time in a porcelain furnace alumina has the spec. grav. 3·999, which is very nearly that of native corundum.

Pure alumina is totally infusible at all moderate temperatures; but exposed to that of the oxyhydrogen blowpipe it fuses into transparent globules, which can be made to resemble the ruby by addition of a small quantity of potassium chromate. EBELMEN succeeded in making minute artificial rubies by heating together in a porcelain furnace a mixture of 1 part of alumina with 3 to 4 parts of borax. The alumina dissolves in the borax, and as the latter is evaporated by the intense heat, crystallizes out as corundum. The addition of potassium chromate, as in the previous case, gives to these crystals the colour of the ruby.

Crystallized alumina is insoluble in all acids, but can be rendered soluble by fusion with potassium or sodium hydrates.

Alumina forms three compounds with water:—

Monohydrate,......$AlHO_2$ or $Al_2O_3 + H_2O$.
Dihydrate,.........$Al_2H_4O_5$ or $Al_2O_3 + 2H_2O$.
Trihydrate,.........$Al_2H_3O_3$ or $Al_2O_3 + 3H_2O$.

The monohydrate is found as the mineral Diaspore. When heated to 360° C. it loses the whole of its water.

The dihydrate was discovered by WALTER CRUM. It is produced by exposing aluminium diacetate to the temperature of boiling water for several days in a close vessel. The acetic acid appears to be liberated, for on subsequently boiling the liquid in an open vessel, nearly the whole of the acid is given off, leaving the alumina still in solution. This aluminous solution is, however, incapable of acting as a mordant, since it forms with dyewoods transparent lakes, in place of the dense opaque lakes which are desired. On evaporating the solution to dryness the dihydrate is precipitated. Dihydrate of alumina is soluble in acetic acid, but insoluble in sulphuric, hydrochloric, and nitric acids. It is converted into the trihydrate by boiling with a caustic alkali.

Aluminium trihydrate is the gelatinous precipitate produced on treating aluminium salts with alkaline carbonates, ammonia, or ammonium sulphide.

Aluminium trihydrate has a strong affinity for organic matters, and when digested with solutions of vegetable or animal colouring matters, forms with the colours insoluble compounds, termed "lakes."

Trihydrate of aluminium is found native as Gibbsite—a translucent mineral with a fibrous structure, soluble in acids.

ALUMINIUM.—*Alumium*, German; *Aluminium*, French. Symbol, Al. Atomic weight, 27·4.—After having succeeded in isolating the metals of the alkaline earths, Davy attempted, but without success, to separate aluminium from its oxide, alumina. In 1826 OERSTEDT formed aluminium chloride by passing chlorine over a mixture of alumina and charcoal, heated to redness in a porcelain tube, and essayed, but in vain, to decompose this salt by potassium and sodium. In 1828 WÖHLER repeated OERSTEDT'S experiment, and by adopting proper precautions to exclude atmospheric air, succeeded in obtaining aluminium, in the form of a grey powder, from its chloride, by igniting the latter with potassium. In 1845 WÖHLER prepared the metal in much larger quantity, and obtained it as tin-white globules.

H. ST. CLAIR DEVILLE, in 1854, succeeded in manufacturing sodium on so large a scale, and at such a price, as to render its use available as a reducing agent. By skilful arrangement of apparatus he turned his cheap sodium to account in the preparation of aluminium. He carried out WÖHLER'S process on a manufacturing scale thus:—

A large iron or copper tube was placed in an unlit combustion furnace constructed for the purpose. Oerstedt's aluminium chloride was then introduced at one extremity of the tube, and at the same extremity a current of dry hydrogen gas was made to enter the tube, and was sustained until the operation was finished. The chloride was now gently warmed by pieces of hot charcoal, in order to drive off any hydrochloric acid which it might contain, and porcelain boats, filled with small lumps of sodium, were inserted in the opposite extremity of the tube. The heat was then rapidly raised until it reached a dull red heat, at which temperature the vapour of the sodium decomposes that of the aluminium chloride. Intense ignition usually attends this reaction. On withdrawing the porcelain boats the aluminium is found adhering in buttons to the earthenware, mixed with sodium chloride and undecomposed aluminium chloride. The boat was now transferred, with its contents, to a porcelain tube, through which hydrogen gas was passed. At a red heat, the double chloride distilled into a receiving vessel attached to the tube for the purpose; the buttons of aluminium were collected, washed with water, and subsequently fused together under a flux consisting of the double chloride.

Another method of obtaining aluminium was also adopted by H. ST. CLAIR DEVILLE with great success. It was founded on a process originally devised by BUNSEN in 1854. By fusing aluminium chloride with an equal equivalent of common salt, he obtained a double chloride ($Al_2Cl_6.2NaCl$), which fused at 360° Fahr. (200° C.). Acting on this body by electrolysis BUNSEN isolated aluminium. DEVILLE took—

400 parts of the double chloride of aluminium and sodium
200 parts of fluor spar or cryolite.
200 parts of sodium chloride.

After carefully drying and mixing, these are laid in alternate layers, with 80 parts of sodium (cut into small pieces), in a crucible lined with alumina, a layer of sodium being put in first. When the crucible is filled a little powdered salt is to be sprinkled on its contents, and the crucible, fitted with a lid, is introduced into a furnace until the reaction, whose occurrence and continuance is indicated by a peculiar and characteristic sound, shall have terminated. The contents of the crucible, having been stirred with a porcelain rod while in their liquefied state (this part of the operation is essential), are poured out on a surface of baked clay or any other suitable material, the flux, &c., on one side, and the metal on the other. The cryolite here chiefly plays the part of a flux; but in 1855 Dr. Percy obtained aluminium directly from this mineral.

When the process is conducted on a large scale the mixture is heated on the floor of a reverberatory furnace. The proportions used being, sodio-aluminic chloride, 10 parts; cryolite, 5 parts; and sodium, 2 parts. The chloride and cryolite are powdered and mixed with small lumps of sodium, the whole being then thrown into the already heated furnace, and the doors and dampers closely shut to exclude air. The action speedily takes place, and becomes so intense that the walls and hearth of the furnace are raised to bright redness, and the mixture itself becomes almost entirely liquid. When the operation is complete, the furnace is tapped at the back, the slag flows out first, and at the last the aluminium. The first portions of slag consist almost entirely of aluminium fluoride (Al_2F_6), and contains minute globules of aluminium, to extract which it is pulverized and passed through a sieve. The fluoride may be used to prepare aluminium.

Cryolite, *i.e.*, aluminium and sodium fluoride ($Al_2F_6,6NaF$), occurs in great abundance at Evijtok in Greenland. It is now very largely used for the preparation of aluminium. The mineral is powdered, mixed with half its weight of common salt, and either placed in alternate layers with 2 parts of sodium in a crucible, or roasted with the same quantity of sodium in a furnace.

The chief advantage in using cryolite is, that the costly and troublesome process of preparing the double chloride of aluminium and sodium is thus obviated. The metal is, however, less pure. Many patents have been taken out for improved processes, but they all apply to mechanical contrivances for economizing the sodium.

GERHARD proposed to decompose aluminium fluoride or cryolite by a current of hydrogen at a red heat. The aluminium fluoride, or cryolite, was placed in shallow earthenware dishes, alongside of which were like dishes containing iron filings, in an oven which had previously been heated to redness. A current of hydrogen was then admitted and the heat increased. Hydrofluoric acid gas was given off and absorbed by the iron filings. This process was, however, ultimately abandoned by its inventor, who reverted to the use of sodium.

No processes of aluminium smelting, except those of reduction by sodium, have been thoroughly successful. The progress of the manufacture of aluminium therefore depends on still more economical methods for producing the alkaline metal being invented. Mr. J. LOTHIAN BELL, of Newcastle-on-Tyne, manufactured aluminium on the large scale for several years, but has of late relinquished the undertaking on account of the limited market for the metal.

PROPERTIES.—The physical properties of aluminium are very characteristic. Its specific gravity is 2·56; after hammering, 2·57. This low specific gravity, being nearly that of the flux employed in fusing it, materially enhances the difficulty of its production. Aluminium is next highest in density to the metals of the alkaline earths. It is malleable, ductile, and sonorous. A bar of aluminium, when struck, emits a clear musical ring; when cast into the shape of a bell and struck the sound is, however, anything but musical; it more resembles that of a cracked pot. The fusing point of aluminium is intermediate between silver and zinc, but nearer to the latter. It resembles silver in its excellence as a conductor for electricity. Its capacity for heat is very great, about six times that of silver. Its chemical characteristics are such as could not have been predicted. Instead of reassuming oxygen, like the metals of the alkalies and alkaline earths, with an energy proportioned to the extreme tenacity of that element when in the state of oxide, aluminium is almost as indifferent to oxygen as are gold and platinum. It is not affected by sulphur as is silver and lead, nor is it acted on, except very slowly, by nitric and sulphuric acids in the cold. Its only solvents are hydrochloric acid and aqueous solutions of potassium and sodium hydrates. The strong affinity between this metal and oxygen before its separation, contrasted with its apparent total indifference afterwards, suggests the possibility that, at the instant of its coming in contact with air, aluminium may receive a fine coating of oxide, a film of transparent sapphire, from the atmosphere, which protects it from all further action. This conjecture is rendered probable by the result obtained on exposing a leaf of aluminium to the oxidizing flame of the blowpipe. The result of the combustion, though apparently a mass of alumina, shows by its metallic lustre, when rubbed in an agate mortar, that the oxygen has not penetrated below the surface.

ALLOYS.—Aluminium forms alloys with nearly all metals. With zinc and iron it forms brittle compounds. With silver it also forms a brittle alloy, unless the proportion of silver be very small—3 to 5 per cent. Silver alloys are used for making many ornamental articles, and are said not to be tarnished by sulphuretted hydrogen.

Aluminium Bronze.—This is the most important of the aluminium alloys. It is a definite compound of copper and aluminium, which has the formula Cu_9Al. This substance is somewhat largely used as a substitute for gold, which it closely resembles in colour. It takes a high polish, is very malleable though hard, and possesses a tenacity equal to that of steel.

AMMONIA. — *Ammoniacal Gas.* — *Ammoniaque*, French; *Ammoniak*, German. Ammonia is synonymous with the *alkaline air* of PRIESTLEY, *volatile alkali*, &c. Formula, NH_3.

Gaseous ammonia was probably known to the ancients, though no record of the fact remains to prove it; still, as the manufacture of ammoniacal salts was a source of trade among the Egyptians, it is very probable the pungency of the gas was familiar to them. Ammonia was noticed by RAYMOND LULLY in the thirteenth century, who prepared it from urine; the name he gave to it was *mercurius vel spiritus animalis*. BASIL VALENTINE, in the fifteenth century, separated ammonia from sal-ammoniac; he termed it *spiritus urinæ*.

The scientific development of this compound remained for Dr. BLACK, who in 1756 first isolated the gas, and proved its distinction from the sesquicarbonate, $(NH_4)_4H_2(CO_3)_3$; PRIESTLEY afterwards, in 1774, with greater accuracy, in a more lengthened investigation, prepared it in a pure state, and discovered more of its properties, and noticed its decomposition by the electric spark. SCHEELE, in 1777, discovered that ammonia contained nitrogen. BERGMANN gave it its present name, ammonia, in 1782; and its true chemical composition was worked out by BERTHOLLET in 1785, and corroborated by his son in 1808.

Ammonia, though not very extensively disseminated in nature, is to be met with in a great many vegetable products; the decomposition of animal matter, either by putrefactive fermentation or destructive distillation, yields it in moderate abundance; it is also found united with acids in many strata of the mineral kingdom. In the atmosphere, very minute portions of ammonia are always present, which exert a most beneficial influence upon vegetation. Volcanic districts are highly productive of ammonia, standing second in this respect only to the guano islands of South Africa. Sea water contains a low decimal percentage of ammoniacal salts; fresh water also holds it in combination, but in an infinitesimal proportion. A perceptible quantity of this alkali, generally combined with acids, is found in mineral springs; soils almost universally contain it—more especially those of the ferruginous and argillaceous class. In many substances where ammonia is apparently absent, a careful and patient investigation may prove its presence. Thus, it occurs in the atmosphere; apparently no ammonia exists in it when performing an analysis, but on examining rain water recently collected in town or country, an expert chemist will always detect it in minute quantity.

Animal excrements, especially those of reptiles, are rich in ammoniacal compounds.

Preparation.—It may be prepared in the laboratory by a very simple process, namely, by heating an ammoniacal salt with quicklime in a retort, and collecting the eliminated alkaline vapour over mercury, or by displacement of air. This operation, though simple, requires—like all those conducted on the small scale—care and skill to obtain a pure product. The decomposition which takes place in the preceding instance, supposing that ammonium chloride had been employed, is the following:—

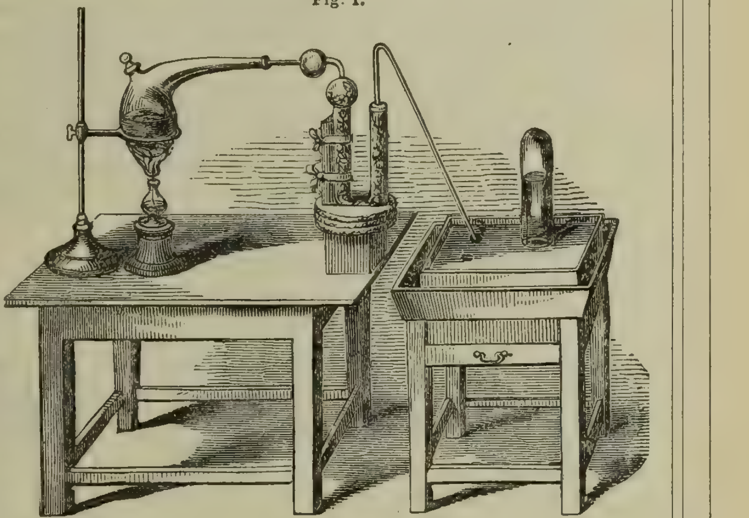
$$\overset{\text{Ammonium Chloride.}}{2NH_4Cl} + \overset{\text{Lime.}}{CaO} = \overset{\text{Ammonia.}}{2NH_3} + \overset{\text{Calcium Chloride.}}{CaCl_2} + \overset{\text{Water.}}{H_2O.}$$

The arrangement in Fig. 1 is well adapted for the preparation of ammoniacal gas: equal weights of the ammonium chloride and quicklime which has been just slaked are intimately mixed, and introduced into the retort, heat is applied, gently at first, and then gradually increased till the gas ceases to be evolved—calcium chloride remains.

One volume of nitrogen and three volumes of hydrogen cannot be made to unite directly, even when passed over red-hot spongy platinum. But on igniting a mixture of hydrogen (in excess), nitrogen, and oxygen, ammonium nitrate is formed.

In a chemical point of view, ammonia is generated in various and curious ways; as, when an excess of hydrogen is burned in the atmosphere, nitrate of ammonia is formed; when iron oxidizes, from the decomposition of water, sesquioxide of iron and ammonia result. A similar combination is formed when hydrates of potassium, sodium, barium, or calcium, are heated in the air, or in hydrogen, with iron, zinc, lead, tin, or arsenic. According to Faraday, this combination takes place even in an atmosphere of hydrogen. Reiset explains its formation in hydrogen as arising from nitric oxide derived from the sulphuric acid used to prepare the hydrogen, and adduces as a corroboration the fact that when iron filings are heated in a strong solution of potassium hydrate, they evolve hydrogen and ammonia, both when heated in air and in hydrogen containing nitric acid, but not in pure hydrogen. When nitrous oxide and an excess of hydrogen are transmitted over platinum black—spongy platinum—in the cold, no ammonia is formed; but if heat be applied it is produced in considerable quantity. A dilute solution of nitro-sulphuric acid—composed of 100 volumes of water, 4½ of sulphuric acid, and 4 of nitric acid—dissolves iron, zinc, or tin, without giving off nitric oxide or hydrogen, although these bodies always result from the decomposition of nitric acid and the solution of the forementioned metals; but in this instance the nascent hydrogen combines with the nitrogen of the nitric oxide, and gives rise to ammonia.

Fig. 1.



Ammonia is a volatile, irrespirable gas, though when diluted with air it may be inhaled. Its odour is extremely pungent; it possesses a strong alkaline taste; turns reddened litmus paper blue, and turmeric paper brown; is very slightly inflammable, and extinguishes those bodies which are in a state of combustion. It is composed of two volumes of nitrogen and six of hydrogen, condensed into four volumes of the gas. The specific gravity of the gas is ·5893, air being taken as unity.

By a pressure of 6½ atmospheres, at the ordinary temperature, it is condensed into a transparent colourless liquid, of 0·731 specific gravity at 60° Fahr. (15°·5 C.); a like result is obtained at the ordinary pressure of the atmosphere, by reducing the temperature 40° Fahr. below zero (—39°·9 C.). It is a very subtle, colourless liquid, which, according to Faraday, freezes into a white translucent crystalline substance at —108° Fahr. (—57°·1 C.). On heating one volume of the liquid to 60° Fahr.

(15°·5 C.), at a barometric pressure of 30·2 inches, it formed 1009·8 volumes of the vapour.

Faraday succeeded in obtaining ammonia in the solid state by exposing the gas to the pressure of 20 atmospheres, whilst reduced in temperature by surrounding the vessel with a mixture of solid carbonic acid and ether.

Ammonia is decomposed with facility by heat in the presence of any substance which contains oxygen easily transferable; hence, if the higher oxidized compounds of nitrogen be brought into contact with ammonia, and both compounds are mutually decomposed, water and a lower oxide, with the occasional elimination of nitrogen, are the result. When transmitted over many metallic oxides at a dull red heat, it is decomposed into nitrogen and hydrogen; the latter abstracting oxygen from the oxide and forming water. It is also split up into its constituent gases by a succession of electric sparks.

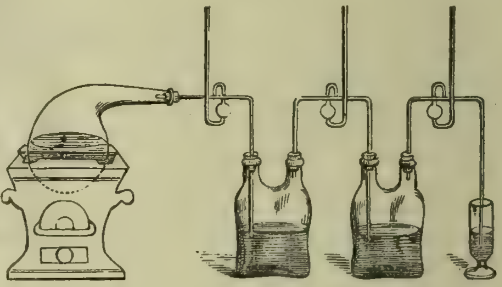
LIQUID AMMONIA.—*Aqueous Ammonia. Salmiakgeist*, German; *esprit de sal ammoniac*, French; synonymous with *caustic ammonia* and *spirit of hartshorn.* Formula, NH_4O.—The preparation of liquid ammonia is one among the many manufactures which have sprung up in consequence of the rapid progress of science and art during the last half century; but it seems to have risen to its present state simultaneously with that of gas-lighting. Considerable quantities of crude liquor ammonia are produced as one of the by-products of the distillation of coal; hence the establishment of factories for the preparation of ammonia and its salts has gradually taken place, from the metropolis to almost every provincial village where gas is consumed. The demand for animal charcoal opened another extensive supply of ammonia, for it is evolved during the destructive distillation of the bones from which the animal charcoal is prepared for the sugar refiner and others; and as soon as the spirit of enterprise and emolument induced the capitalist to turn his attention to the manufacture, various other sources were discovered which yielded this alkali. The principle on which ammonia is generated on the large scale differs in nothing from the processes already stated; and the formation of the solution of the alkali rests upon the property which water possesses of absorbing it. Water, at a temperature of 50° Fahr. (10° C.), condenses about 670 times its bulk of ammoniacal gas, Davy (*i.e.*, nearly half its weight), 780 according to Thomson; by this retention the bulk of the solution is increased considerably, so much so, that 6 volumes of water, on becoming saturated with the gas, increase to 10 volumes, and the specific gravity of the liquid is reduced from 1·00 to 0·875.

Liquor ammonia is prepared in the laboratory by taking a mixture of 1 part of sal ammoniac with 1¼ part of slaked lime, and 1½ part of water, and introducing it into a glass or earthenware retort, the neck of which is connected with a series of Woulfe's bottles, described at page 78—one of which contains a little water to arrest impurities; the second, a weight of water equal to that of the ammonium chloride used, space being allowed for expansion of the liquid; a third is useful to stop the uncondensed ammonia which would otherwise escape into the air. The ammoniacal solution in the last two bottles is pure. It is necessary that the lime used should be slaked in about 4 parts of water, previous to its being mixed with the powdered ammoniacal salt, as by that means the ammonia will be more freely disengaged, and with less heat than when only a small quantity of moisture is present.

Fig. 2 is a representation of an apparatus which answers the purpose remarkably well.

During the decomposition the heat should not be too briskly applied, and in no case should the bottom of the retort be raised to redness, as portions of the salt would be sublimed without being decomposed; and by passing over to the first bottle, would render its contents unfit for use. To guard as much as possible against the sublimation of the salt, the tube connecting the retort and first bottle should have a considerable calibre; and it is often advantageous to append a large bulb or balloon between the mouth of the retort and first condenser, in order that any portion of the sublimed salt which might be driven off towards the end of the operation, may be arrested before it is carried into the ammoniacal liquor. The greatest precaution is to be taken in having all the connections air-tight, to prevent the escape of vapour. When the whole of the ammonia is driven off, it is necessary to raise the temperature a little higher than usual to fuse the chloride of calcium; and as soon as this takes place, the retort should be disjoined from the condensing bottles, and the fused salt poured out as speedily as possible. Very often the retort breaks at this part of the operation, in consequence of a layer of the salt solidifying upon its neck, which on being exposed to the air readily absorbs moisture, and partly dissolves; the solution thus formed cools considerably, and on penetrating through the undissolved portion of chloride of calcium to the retort, which still retains a high degree of heat, the particles with which it comes in contact are suddenly contracted, and the retort cracks. Should the retort escape fracture at this part of the process, it generally happens that it is broken when the heat is applied for a second operation; hence it is rare to find a retort, even when carefully handled, that will stand two operations.

Fig. 2.



Uses of Ammonia.—Ammonia is in daily requisition as a reagent for the analytical chemist. It offers peculiar facilities in the preparation of many compounds on account of its great volatility, as also that of its salts, and as being an almost universal precipitant of the oxides of the heavy metals. In medicine, ammonia is used to a moderate extent to alleviate spasms, for rousing the vascular and respiratory system, as an antacid, and in various other cases. It is extensively employed in bleaching and calico-printing, in colour manufactories, for making artificial manures, and other important trades.

When ammonia is manufactured on the large scale from ammoniacal salts, the sulphate of the alkali is for the most part preferred; but there is no material deviation from the directions already laid down, except that another kind of apparatus is used, to avoid the loss of retorts which is incurred when preparing it in the laboratory. It is particularly necessary, when working upon the large scale with condensers in the form of Woulfe's bottles, to have the joints well luted; this is effected by covering each connection with a paste made of white of egg and chalk intimately ground. A better composition is produced by blending wax, resin, and turpentine together; this should be applied upon the connection of the tubes and tubulures of the condensers in moderate thickness. If this point is not attended to with care, the pressure upon the gas forces it through into the atmosphere, causing the workmen considerable annoyance till arrested.

Fig. 3.

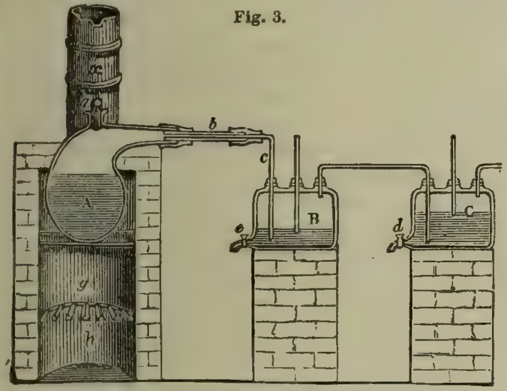


Fig. 3 is a vertical section of an apparatus which answers well for the preparation of ammonia on a large scale.

A is an iron retort, placed in sand, over the fire *g*, of which *h* is the ash-pit, and *x* the chimney; *a* is the stopper, and *b* an iron pipe connected to the neck of the retort, and reaching some distance from the furnace to the end of the tube, *c*, which may be either of glass or lead. B is the first condensing vessel, and is supplied with three tubulures, through the middle one of which a safety tube is inserted. *e* is a stopcock and pipe, by which the contents of B are drawn off when requisite. This vessel is left nearly empty, for the purpose of purifying the gas of any traces of ammoniacal salt which may be carried over, and also for retaining traces of oily matters which are invariably present, either from the impurity of the salt employed, or from the grease with which the stopper is smeared to prevent it from adhering too tightly in its place. B is connected with other condensers, of which only one, C, is seen in the figure; these vessels are filled to about three-fourths of their capacity with water, and so rapid is the absorption of the gas, that scarcely a trace of ammonia escapes from C till the solution contained in it is completely saturated.

When this happens, the solution of ammonia is drawn off by the stopcock, *d*, and the very weak liquor in the third condenser supplied instead, or it is recharged with a fresh quantity of water.

In this process it is very easy to produce, at each operation, an ammoniacal liquor of any standard strength, by furnishing each condenser with a glass gauge pipe, graduated into equal parts, showing the bulk of liquid in the interior. Whatever be the quantity of water introduced, it expands in the ratio of six to ten, as before stated, on being completely saturated with the alkaline vapour, or in less proportion according as its gravity is reduced. At the first working, the measure of water employed is noted, and also the proportion of expansion, till it approaches that point which, by calculation, is found to correspond with the strength of the liquid required; this may be corroborated by drawing off portions repeatedly, and taking their density, and from this number the quantity of ammonia is ascertained by the aid of tables, which will be found further on. As soon as the exact point is gained, the gauge is scratched at the level of the liquid, and this one test will serve for all future operations where the ammonia is to be made of the same strength; but it is necessary that the bulk of liquid should be always equal to that used in the first experiment.

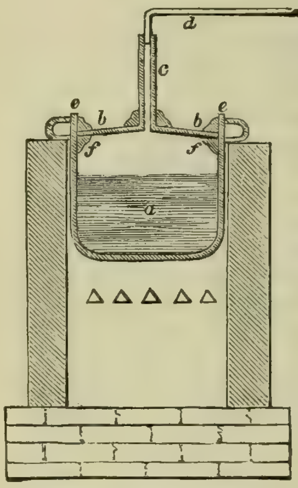
When gas ceases to be evolved from the mixture in the retort, the fire is partly urged, and the stopper removed by means of a lever. If the stopper be so firmly fixed that it cannot be readily displaced, a cloth moistened with cold water should be carefully wrapped round it, without touching the neck of the retort; this refrigeration causes a contraction in its particles, and will enable the operator to remove it with facility. The residue—which is fused chloride of calcium, in the event of the chloride of ammonium being used—is then ladled out. Should sulphate of ammonia be operated upon considerable quantities of water are employed, and the distillation should never be allowed to proceed to dryness, as in such a case the sulphate of lime formed would constitute a concrete on the bottom of the retort, which could not be removed without much labour and loss of time.

All the ammoniacal impurities which have collected in B during the first distillation are drawn off, and introduced into the retort in the second operation, to obtain the ammonia which they hold, and a small quantity of fresh water is substituted, to cover the lower end of the safety tube, as in the preceding operation. This apparatus, when once erected, will last for a long time.

A modification of the foregoing apparatus represented in the annexed cut—Fig. 4—is sometimes employed.

a is an iron kettle, to which a metallic lid, *b b*, is

Fig. 4.



adapted, resting upon blocks or ledges, *f f*, in the interior of the vessel. The lid is rendered air-tight by means of other bars of metal, *e e*, which are soldered fast on the outside over the interior ones. From the middle of the cover an iron pipe, *c*, rises, to the orifice of which another pipe, *d*, bent at right angles, is soldered, for the purpose of conducting the ammoniacal vapour to the condensers, which are similar to those already described. A much larger quantity of water must be used in this apparatus than in the preceding one; and as distillation advances, it is necessary to keep up the supply throughout the process, that the solder may not melt, a circumstance which would happen were this precaution overlooked.

As the demand for ammonia and its salts became greater, its manufacture received an additional impetus, and many patents have been granted for its preparation; most of them, however, relate to the production of the salts of ammonia.

Mr. Young, in 1841, took out a patent for preparing ammonia from guano; the method which he recommends is the annexed:—The retorts are filled vertically with two parts by weight of guano, and one part by weight of hydrate of lime, or other caustic alkali, and the whole is intimately mixed by the aid of an agitator placed in the retort. Having well mingled the materials, the retorts are moderately heated, and this heat is gradually increased to redness. The combined action of the heat and alkaline compounds disengages all the ammonia, whether it be in the form of salts or other complex bodies, such as urea or uric acid, and the gas thus liberated is received into a condenser filled with water. Other gases and fluids are evolved together with the ammoniacal vapour, the uncondensable portions of which pass through the condenser unaffected.

An ammoniacal solution is obtained by the destructive distillation of bituminous schist, by Count de Hompesch, who rendered it available for the manufacture of ammoniacal salts.

The method adopted by Watson for manufacturing ammoniacal liquor from gas liquor is as follows:—The gas liquor is run into a capacious retort, and a suitable quantity of slaked lime added—the amount being determined by the quality of the crude liquor; heat is then applied, and ammonia, tolerably pure, distils over, which, on being received in a vessel of cold water, forms an ammoniacal liquor. When considerable quantities of steam are observed to pass over with the vapour of ammonia, the strong alkaline solution already formed is removed; that which is collected afterwards, by continuing the distillation, is weak or impure, and is returned to the boiler, with a second charge of lime and crude liquor, to undergo another distillation. The first portion from the previous operation is introduced into the retort, mixed with a small quantity of lime if necessary, and as soon as the disengaged vapour carries steam with it, the strong liquor in the condenser is to be drawn off as before. The distillation is continued as long as it yields ammonia, and this secondary product is returned to the retort as before. The first portion of the second distillation is a concentrated liquid of sufficient purity for all ordinary purposes of scouring, cleaning, &c., but it may be still further improved by distilling a third time, in the same way as already directed, observing that the portion of solution which is made by the absorption of the ammoniacal gas is preserved, and the residue transferred again to the retort.

A great step in advance in the manufacture of ammonia on the large scale, was made by Newton in 1841; it consisted in the application of Coffey's still, described at page 80, but with a few modifications to adapt it to the distillation of the gas water. By its use the ammonia may be produced of any density up to its most concentrated state, and consequently of corresponding purity. Having made the reader already acquainted with the still in its application to the whisky trade, it will be unnecessary to enter into lengthened details; those specific alterations which are peculiarly required by the operation will, however, be pointed out. The number of diaphragms in the apparatus is increased or diminished according to the strength of the product which is to be produced, and the whole apparatus may be constructed of wood lined with sheet lead, having the diaphragm plates in the interior of the analyzing column formed of perforated sheet-iron. Each of the sheets is supplied with several small valves, so weighted as to open upwards whenever the elastic vapour below the plate exerts more than a certain amount of pressure upon them. The ammoniacal crude liquid, which enters at the top, passes downwards through each diaphragm successively, by means of a pipe rising about 1 inch above the level of the plate, the lower end of which is encased in a cup fixed upon the next diaphragm. The pipe must be sufficiently capacious to carry off all the liquid which enters at the top; and as the solution descends it fills the small cup, and prevents the vapour from ascending at this part of the plate. Steam, as usual, is the medium which effects the elimination of the volatile body. According as the ammonia is to be procured, the supply of liquor and the entrance of steam beneath are regulated. When it is necessary that the ammonia should depart from the top of the rectifying column in the form of gas, the flow of liquid should be in proportion to the ascending steam, in order that the liquor in the top diaphragms may remain at little more than the normal temperature of the atmosphere, but become hotter as it falls towards the under reservoir, where it is retained for some hours at a boiling heat, to expel all the alkali. On the contrary, when it is necessary that the ammoniacal vapour should be in company with much steam, the stream of liquid entering is elevated to nearly its boiling point in the top diaphragms, by means of the larger volume of steam which is admitted from the boiler. Concentrated or dilute solutions of ammonia may in this way be obtained at once from salts, the acids of which are removed in the usual manner by lime or alkali; a product of considerable purity is also derived from the ammoniacal liquids formed by the distillation of bones or other animal matters; but before submitting such liquids to the action of the heat, it is necessary to remove most of the impurities and the combined acid by the action of lime.

It is customary to have the diaphragms bent upwards, alternately, at opposite sides, so as to conduct the liquid from right to left, and conversely, till it reaches the bottom.

Carbonic acid gas, and other volatile compounds which do not impair the use of ammonia in certain applications, may in using this still be given off with the ammonia; but in this case as much steam should be generated as will prevent the absorption of the ammonia gas by the carbonic acid.

LAMING recommends that the solution of ammonium carbonate, as obtained from bones, should be decomposed by means of chloride of calcium, instead of the mineral acids which are usually employed for that purpose; carbonate of lime is formed, and chloride of ammonium remains in solution. After filtering or siphoning this liquid, he boils it for an hour, by which treatment any gaseous impurities are expelled. As soon as the liquid has cooled, it is agitated, first with sufficient hydrated oxide of iron to precipitate any hydrogen sulphide (H_2S) that may still remain, and next with enough lime to saturate the whole of the combined hydrochloric acid; it is then distilled. By this treatment a tolerably pure solution is produced.

It is to be observed, that when ammonia is prepared on the large scale according to the method first described, the dry salt and lime are often mixed in the retort, and as operations are about to commence, a quantity of water is added for the purpose of slaking the lime, and preventing the mass adhering to the bottom of the retort; by this means so much heat is generated that a considerable quantity of the ammonia is driven over to the receivers, and thus fuel is economized. To prevent the residue hardening when the distillation is carried to dryness, it is customary to add a few spadefuls of common salt to the mass.

An ingenious apparatus, which may be taken as typical of that now commonly employed for extraction of ammonia from gas liquor, &c., was recently devised and patented by ELWERT and PACK. The form of apparatus will be readily understood by the following description referring to the accompanying drawings. (Figs. 5, 6, and 7). The same letters refer to the same parts in each figure.

A vessel capable of holding the charge of ammoniacal liquor is so fixed that it may receive the liquors from the tank or reservoir of crude ammoniacal liquor. In this vessel the gas liquor is mixed with the proper quantity of lime, and then run into a boiler.

On the application of the fire to the boiler the ammoniacal vapour as it escapes is led by a pipe back into the first vessel, and allowed to escape into the liquid at its lowest portion; as the gas rises it absorbs fresh portions of ammonia, and thus enriched by the ammoniacal liquor, is led into a condensing chamber, the more condensible portion running back into the first vessel. The more volatile vapour is carried through a refrigerating worm to a condensing tank where the hydrocarbons, some free ammonia, and sal-ammoniac is retained. The purer and uncondensed vapour passing on is conducted into vertical purifiers filled with charcoal, and thence into the stock condensing chamber.

On the dome or upper part of the wrought-iron boiler A is adapted the tube *a*, *a*, which passing upwards for a certain distance is then turned downwards, and enters through a tight joint into the vessel A_1 nearly to the bottom; it is then carried along nearly the whole length of A_1, and is pierced with numerous holes for the escape of the gas passing from the boiler A into this pipe or tube *a*, *a*.

On the dome of the vessel A_1 is adapted the tube *b*, *b*, turned down as a siphon, the other branch going to within 12 inches of the bottom of the vessel B, which is in communication with A_1 by the tube *l*.

On the cover of the vase B is fixed the tube *c*, which leads the aqueous ammoniacal vapours into the coil of the refrigerator C. The tube *c*, when it leaves the refrigerator, is carried to within 8 inches of the bottom of the vessel D, fitted with a safety tube *d*, and a cock *s*, opening a communication by the tube *p* between the vessel D and the boiler A_1.

In the vessel D are deposited the aqueous ammoniacal vapours condensed by the worm, whilst the ammoniacal vapour passes by the tube *e* to traverse four cast-iron tubes, E, E_1, E_2, E_3, communicating by the tubes *f*, f_1, f_2; these four tubes, open at each end, are fitted with rims so that each end may be closed with a tight fitting cast-iron cover.

From the tube E_3 the ammoniacal vapours are carried by the leaden tube *g* into a lead condensing cistern G, fitted with a funnel-shaped safety tube *h* and a cock for emptying at *t*; the bent tube *i* takes the non-condensed gas in G into the vessel H, which is also fitted with a tap for emptying a funnel-shaped safety tube *j*, and a tube *k* for the last uncondensible portions of the gas; the latter should be led away from the factory.

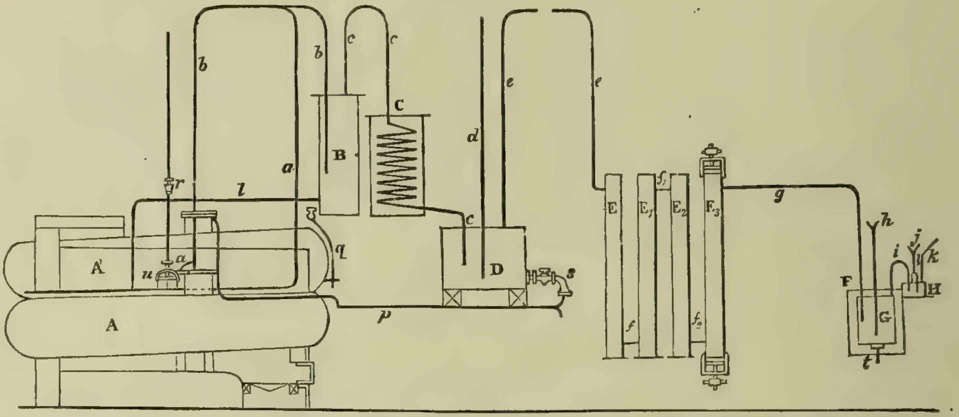
The crude ammoniacal liquors are introduced by the tube and cock *q*, which is in communication with a reservoir above the level of the tank A_1. The capacity of the boiler A_1 is about 300 gallons. The milk of lime is thrown in hot through the hole *r*.

The emptying of the vessel A_1 into the boiler A is effected by the tube and valve *m*, to clear the tube *m* of any matter which might choke it. The rod *o* is fitted in a stuffing box, which allows it to be passed along the pipe without loss of any vapour or liquor. The boiler A is emptied by the tube and valve *n*.

To prevent the formation of vacuum the boiler A is fitted on the tube *a*, *a*, with a small tube in connection with the vessel *u*, which latter carries the safety tube and cock *r*.

The vessel G is placed in a reservoir made of sheet iron, F, containing cold water or a cooling mixture, as the vessel G becomes otherwise too warm by the condensation of the ammoniacal vapour into the water.

Fig. 5.

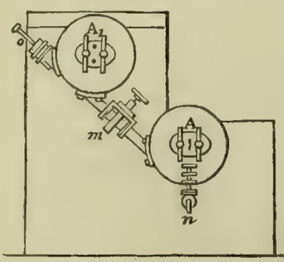


On the face of the boiler A, about 60 centimètres from the bottom, a small hole is made which is closed with a wooden peg, by means of which it can be ascertained when the vapour of ammonia has been completely driven off.

The mode of working the apparatus is as follows:—The man-holes of the boilers being closed, the valve *n* of the boiler A is closed, the valve *m* is opened, the refrigerators C, F, are filled with cold water, the four tubes E, E_1, E_2, E_3, are packed or filled with freshly burnt charcoal, the covers screwed on and luted with linseed meal. In the vessel G is placed 8 or 10 gallons of pure water, and the vessel H is also filled with water through *j*.

After these preparations the cock *q* being opened, 300 gallons of crude ammoniacal liquor is run into the vessel A_1, and at the same time by the hole *r* enough milk of lime to set free all the ammonia in the charge.

Fig. 6.

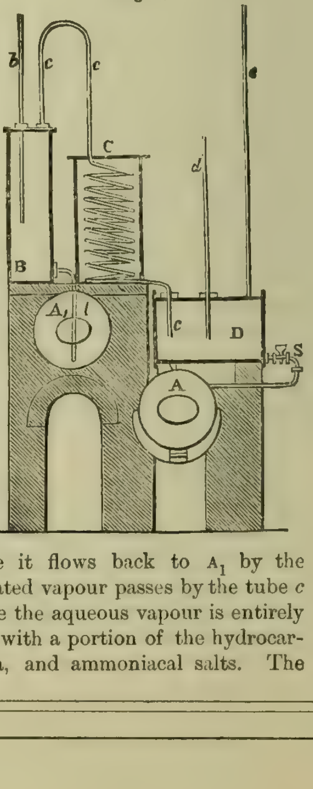


When the crude liquor mixed with the milk of lime has run into the boiler A, the cock *v*, the valve *m*, and the hole *r* are closed, and the fire is lighted, the heat from which passing under the first half of the boiler A returns under the other half in its passage to the chimney.

As soon as the contents of the boiler begin to boil the air is expelled, and bubbles through the vessel G and H: the boiler A_1 and the tubes *b* and *c* become hot; the air has then been expelled and it is time to charge the boiler A_1. The cock *q* is then opened, the vapour is cooled by the liquor running into A_1 and produces a vacuum, which draws the surplus liquid in D along the tubes *c* and *p* into the upper vessel A_1, at the same time that the air enters by the tube *d*. When A_1 is charged the cock *q* is closed, and the cock *v* opened, and through the hole *r* the charge of milk of lime is added, the contents of A_1 are well stirred with a rod, the hole *r* closed, and the fire made active.

The aqueous ammoniacal vapour of the boiler A, escaping by the small apertures in the horizontal part of the pipe *a*, *a*, agitates the liquor in A_1 and rises through the liquid much richer in ammoniacal vapour. This vapour, passing by the tube *b* into the vessel B, partially condenses and loses its aqueous vapour, which with some of the ammoniacal salts deposits in the vessel, from whence it flows back to A_1 by the tube *l*; the concentrated vapour passes by the tube *c* into the worm, where the aqueous vapour is entirely condensed, together with a portion of the hydrocarbons, free ammonia, and ammoniacal salts. The

Fig. 7.



liquid accumulating in the vessel D assists towards the end of the operation, when the vapours are more charged with ammoniacal salts, to wash these vapours and retain the salts. The uncondensed vapours pass by the tube *e* to the charcoal purifiers E, E_1, E_2, E_3; the charcoal absorbs all the hydrocarbons, and pure ammoniacal gas escapes from the last purifier by the pipe *g* into the vessel G, where the pure water absorbs the vapour till the liquid has acquired the desired strength. The atmospheric air escapes by the tube *i* into the liquid in the vessel H, which absorbs the last traces of ammoniacal vapour, and passes by the tube *h* outside the factory.

During the operation the refrigerators C and F must be kept constantly cooled.

When the liquor in the boiler A contains no more ammonia it is run off by the valve *n*; and A is again charged from A_1, the cock *v* shut as before, and the crude charge let into A_1 again. The aspiration draws the liquid from the vessel D by the tube *p* and the tube *c*, thus clearing away any deposit in the tubes every time the boiler is charged.

During the time A_1 is being charged the charcoal purifiers are repacked, the liquid ammonia is drawn off from the vessels G and H, and replaced with pure water as before. If the water used in G and H is not distilled water, the ammonia liquor when drawn from G and H must be set aside to deposit the salts of calcium, aluminium, and magnesium; but with pure water the charge is ready for immediate delivery.

The time occupied in the operation is from four to five hours.

Liquid ammonia is of different strengths, according to the more or less complete saturation of water with the gas. As the quality of the solution depends mainly upon the available ammonia it contains, it is the duty of the manufacturer, as well as of the purchaser, to be acquainted with its amount. Specific gravity tables have been constructed by various chemists, for the purpose of ascertaining the value of ammoniacal solutions. In the formation of these tables a great many experiments were performed with liquids of various densities, for the purpose of arriving at their content of ammonia, and the amount corresponding to the intermediate gravities calculated according to the known properties of this alkali.

Of these, the results of DALTON, DAVY, and URE are generally preferred. According to DAVY, the appended table expresses the percentage in every hundred parts of liquid:—

Specific gravity of the liquid.	Percentage amount of ammonia.	Specific gravity of the liquid.	Percentage amount of ammonia.
·8750	32·50	0·9435	14·53
·8875	29·25	·9476	13·46
·9000	26·00	·9513	12·40
·9054	25·37	·9545	11·56
·9166	22·07	·9573	10·85
·9255	19·54	·9597	10·17
·9326	17·52	·9619	9·60
·9385	15·88	·9692	9·50

DALTON attaches the boiling point and the volume of vapour in the mixture:—

Specific gravity.	Grains of ammonia in a hundred of the liquid.	Boiling points.	Volumes of gas in one volume of the solution.
0·850	35·3	26°	494
·860	32·6	38	456
·870	29·9	50	419
·880	27·3	62	382
·890	24·7	74	346
·900	22·2	86	311
·910	19·8	98	277
·920	17·4	110	244
·930	15·1	122	211
·940	12·8	134	180
·950	10·5	146	147
·960	8·3	158	116
·970	6·2	173	87
·980	4·1	187	57
·990	2·0	196	28

The following is the table of the strength of caustic ammonia compiled by URE:—

Specific gravity.	Per cent. of ammonia.	Specific gravity.	Per cent. of ammonia.
0·8914	27·940	0·9363	15·900
·8937	27·633	·9410	14·575
·8967	27·038	·9455	13·250
·8983	26·751	·9510	11·925
·9000	26·500	·9564	10·600
·9045	25·175	·9614	9·275
·9090	23·850	·9662	7·950
·9133	22·525	·9716	6·625
·9177	21·200	·9768	5·500
·9227	19·875	·9828	3·975
·9275	18·550	·9887	2·650
·9320	17·225	·9945	1·325

The gravity may be taken by an ammoniometer, or spirit hydrometer, or in a specific gravity bottle, which, at the ordinary temperature and pressure, holds 1000 grains of water.

Prepared by the usual method, ammonia is liable to be impregnated with chloride of ammonium and ammonium sulphate, which are sublimed, and carried over mechanically. They may be detected by neutralizing a portion of the alkaline solution with pure nitric acid, and testing the liquid, divided into two portions—one with barium chloride, for sulphuric acid; and the other with silver nitrate, for hydrochloric acid. A white precipitate, or milkiness, will in either case prove the presence of the acid sought. Should any lime or calcium chloride be carried over, which is rarely the case if ordinary precautions have been taken, it may be detected by evaporating the solution to dryness, and heating the residue to dull redness for a short time, to expel any traces of ammoniacal salts that may be present; the impurities will remain. If volatile organic substances be mixed with the compounds from which the ammonia is derived, they may be carried over with the vapour and condensed in the receiver; such matters are detected by the brownish or dark colour they communicate to the solution. These impurities may, for the most part, be removed by filtering through animal charcoal. The charcoal absorbs some of the ammonia, and should be washed occasionally with water to abstract it; the washings may afterwards be distilled.

Chloride of Ammonium.—*Sal-ammoniac*, *ammonium chloride*, *muriate of ammonia*. *Chlorure d'ammonium*, or *chlorure ammoniaque*, French; *chlorammonium*, *salmiak*, *salzsaures ammoniak*, German. Formula, NH_4Cl.—The manufacture of chloride of ammonium was first practised by the Arabians, although it has been attributed to the Egyptians. The term *sal-ammoniacus* is very ancient; but whether the ancients, at the period in which this term was used, applied it to our chloride of ammonium is doubtful. Pliny and his contemporaries were unacquainted with sublimation in any shape; and it is a fact, that even the process of lixiviating earths, or crystallizing saline substances from their solutions, was so ill understood that the native compounds, however impure, were employed in the manufacture of inks, colours, &c. From the many evidences adduced by Beckmann, it is almost certain that the sal-ammoniacus of the ancients was common *rock salt.* Indeed, the uses to which it is stated the sal-ammoniacus was applied, leaves no doubt that the chloride of ammonium was not meant. The Arabian philosophers were the first to furnish an account of true sal-ammoniac. Geber describes its preparation and its purification by sublimation.

Sal-ammoniac was an article of trade about the year 1410; but the purposes to which it was applied, or the mode of its preparation in Egypt at that period, have not been recorded. In the sixteenth century many of its properties were known, particularly its behaviour with nitric acid, by which aqua-regia is formed.

The younger Geoffroy was the first to show that sal-ammoniac consisted of hydrochloric acid and volatile alkali, and that it could therefore be produced in Europe by sublimation. An account of the sal-ammoniac—ammonium chloride—manufactories at Damayer, in the Delta, was given in 1720 by a Jesuit named Sicard. It is uncertain at what period the manufacture became general in Europe. Large manufactories of this article were at work in Scotland so early as 1750.

Chloride of ammonium was discovered in the mineral products of volcanic districts in the fifteenth century. It is generally met with, sublimed among other volatile bodies, in the fissures of lava, particularly at Vesuvius, Etna, in the Island of Volcano, and at the Solfatara, near Naples. Small quantities of it have been found in the vicinity of ignited coal-fields, as at St. Etienne in France, in Scotland, and at Newcastle. A variety, possessing a greyish-white colour, of a conchoidal fracture, has been mentioned as occurring in Bucharia. The native salt is generally massive, has a fibrous texture, is sometimes feathery, in crusts, and in minute cubic and octahedral crystals; its colour, when pure, is white. It is sometimes transparent, sometimes opaque; externally dull or glistening, and internally shining or vitreous. This salt has no smell, but a pungent and saline taste; its specific gravity is 1·5. It is soluble in 2·72 parts of water at 66° Fahr. (18°·8 C.), with great reduction of temperature, and in its own weight of water at 212° Fahr. (100° C.); it does not attract moisture on exposure to the air. Ammonium chloride is, when exposed to the air, partially decomposed, it loses ammonia, and becomes acid to test paper. When heated it completely volatilizes in white fumes without fusing. After sublimation it forms very tough crystalline masses, which can scarcely be powdered, and emits, when triturated with lime, a strong ammoniacal odour.

Two samples, from Vesuvius and Bucharia, yielded according to Klaproth the following results:—

	Vesuvius.	Bucharia.
Ammonium chloride,........	99·5	97·5
Ammonium sulphate,........	0·5	2·5
	100·0	100·0

Chloride of ammonium is prepared in the laboratory by neutralizing pure ammonia with hydrochloric acid: or by transmitting a stream of ammonia gas into hydrochloric acid till saturated, and then evaporating the solution and crystallizing out the salt. The properties of the chloride, in a chemical point of view, are not very distinctive, though in a manufacturing light the compound is highly important. Its chief characteristics will be mentioned after the reader becomes familiar with the chief methods followed in its preparation on a large scale.

In Egypt, which undoubtedly was the great seat of its manufacture from the thirteenth to the middle of the seventeenth century, and from whence all the European markets were supplied, it was obtained by the following process, which indeed is still in use.

The great source of sal-ammoniac in Egypt is the dung of the camel, which is dried by plastering it upon the walls, and then used for fuel, which is very scarce in that country. A fire of this material evolves a thick smoke charged with chloride of ammonia, a large part of which is condensed in the soot. The latter is carefully collected throughout the country, particularly in the Delta district, and brought to the sal-ammoniac factories for the purpose of distillation. The first accurate account of the manner of manufacturing the salt in Egypt was transmitted thence to Europe by Lemère, French consul at Cairo, in 1770. The soot was put into large round glass bottles, which were externally coated with loam, in order that they might the better bear the heat, and were then ranged in a long ridge or terrace, in such a way that only their necks were exposed to the air, while the flue from the furnace circulated freely round each of them. These bottles, or globes, were generally 1½ foot in diameter, and the neck about 2 inches long: 40 lbs. of soot formed the charge, filling each of them to within 4 inches of the neck. From this weight of material about 6 lbs. of the salt were obtained. A fire, made of dry camel's dung, heated the range of bottles; on the second day, when the bottles became heated, the salt commenced subliming, and much care then became necessary on the part of the attendant to keep their necks free for the passage of the uncondensed vapours. Towards the conclusion of the operation, the fire was urged to bring the globes to incipient redness, that the last portions of the salt might be disengaged. At the end of the third day the fire was extinguished, and as soon as the globes cooled they were taken out, broken, and the cake of salt abstracted, and in this form was exported to Europe. On breaking the bottles, a nucleus of the salt was found surrounded by a fixed pulverulent substance, which was taken out and mixed with fresh portions of the soot in the succeeding operation. Considerable quantities of the salt were evidently lost by this mode of preparation.

In India ammonium chloride was manufactured in much larger quantities than in Egypt. The cakes from the subliming vessels had the form of a sugar loaf, and weighed about 15 lbs. These loaves were composed of three distinct layers; the upper of each was impure, and was generally cut off. Egyptian and Indian sal-ammoniac was a dull, spongy, and greyish mass, considerably inferior to the sal-ammoniac now made; nevertheless, on account of its scarcity, it commanded a price more than six times that of pure ammonium chloride at the present time.

Before the introduction of gas-lighting, the ammonium chloride made in Europe was obtained from offal, or from the refuse cake of oil presses, either by allowing the ammoniacal compound to undergo putrefactive fermentation, or by submitting it at once to destructive distillation; the latter course was adopted in Germany. In this country the soot deposited from pit coal was at one time employed to yield the salt. The distillation of pit coal affords considerable quantities.

At present ammonium chloride is extensively produced as a bye product in the manufacture of bone charcoal. The bones are distilled in iron retorts. The accompanying engravings may be taken as typical of the arrangements commonly made. Figs. 8, 9, and 10 represent a furnace for distilling bones, and obtaining the ammoniacal compounds and the oil from them.

Fig. 8.

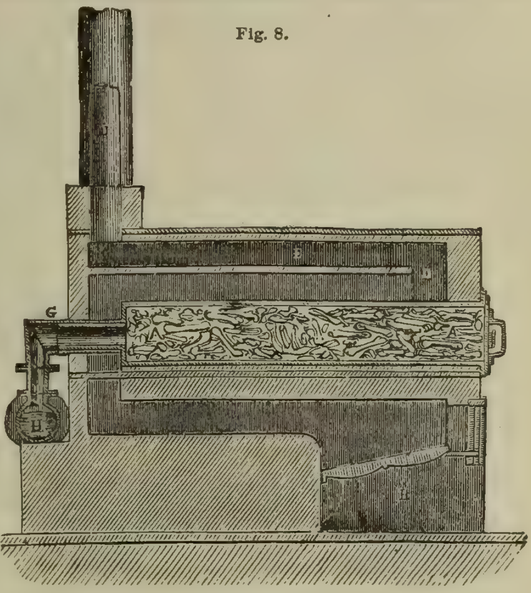


Fig. 8 is a longitudinal vertical section of the retort, A A, for holding the bones, showing its position in the dome of brick which encloses the fire, B. The flue, after passing round the retort, is shown to advance to the front of the furnace, as at D, before it returns by the arch, E, and enters the chimney, J, at the back. The pipe, G, emerging from the far end of the retort, enters the cylinder, H, Fig. 10, into which it conducts all the eliminated products of the distillation.

Fig. 9.

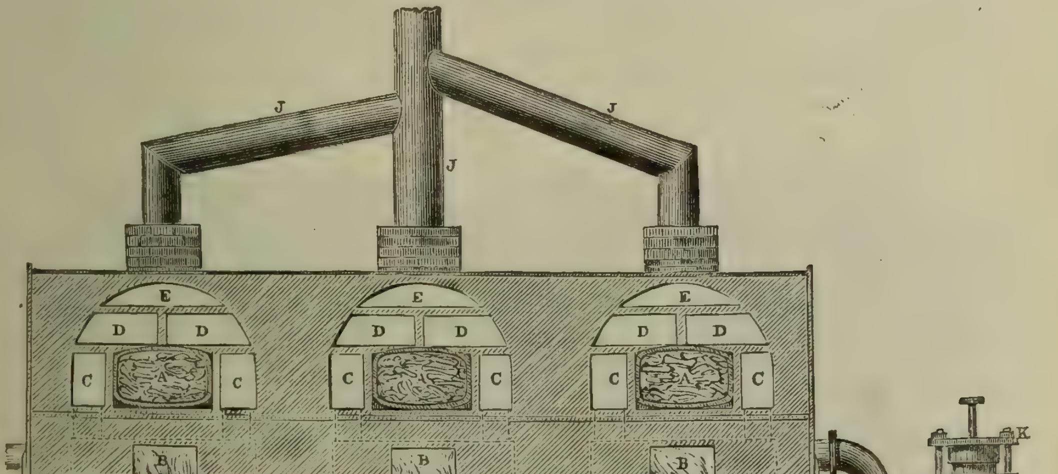


Fig. 9 is a vertical section of the series of retorts and furnaces, made at right angles with Fig 8, and parallel to the front elevation. A A A are the retorts, and B B B the furnaces, placed immediately under, though not in contact with them. This figure shows more clearly the circuitous passage of the flame and heated strata of vapour from the fires, B, surrounding the retorts laterally at C C, and horizontally at D D, above, as well as at the fireplace below. When the heated air reaches the front of the chambers, D, it returns, as seen in Fig. 8, by the space, E, to the chimney, J. On the right is shown the safety-valve, K, by which air is admitted into the apparatus when the distillation of a charge has been finished; and at the opposite side is seen a portion of the pipe which conducts the uncondensed vapours to the refrigerator.

Fig. 10.

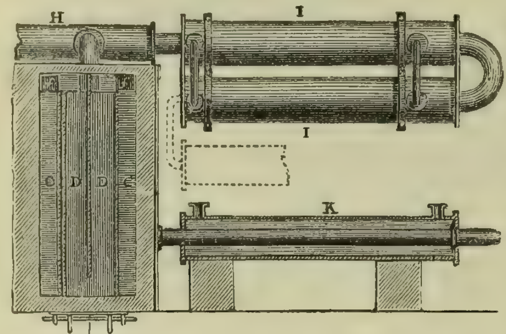


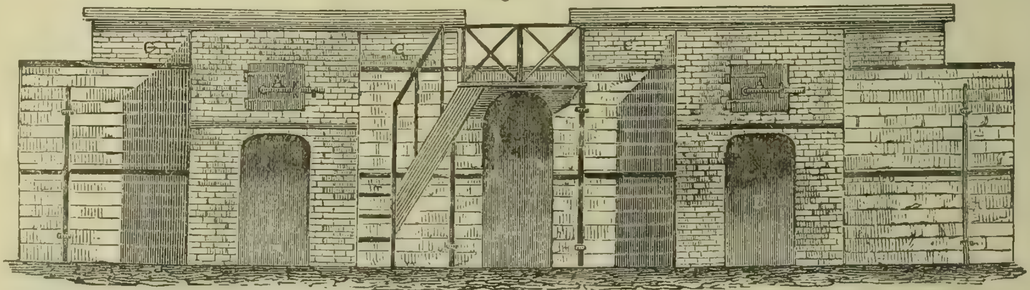
Fig. 10 exhibits a horizontal section of the flues surrounding the retorts, with a view of the condensing pipes from above. In this figure the flues are seen to rise from the canals, C C, to the chambers, D D, at the back, through *f f*, and from D they pass off similarly to E, at the front, as in Fig. 8. The condensing pipes, H and I I, are seen vertically; the latter are rather inclined, and enclose the entrance pipe, while the surrounding space is kept replenished with cold water, which enters at the lower, and is discharged at the upper pipe as it becomes warm. This arrangement is shown in the section, K. From the end of the last refrigerator, the condensed products are discharged into a suitable receiver, where the oil collects at the top in a layer, and is skimmed off, leaving the ammoniacal liquor, to which hydrochloric or sulphuric acid is added in proper proportion till the solution is neutralized; the liquid is then pumped, or otherwise transferred, to the evaporating pans to be concentrated.

Fig. 11 represents a range of such evaporating pans. A A are the fires, B B the ash-pits, and C C C C the evaporating pans, which are about 9 feet square, and 18 inches in depth, and are formed of sheet-lead; their front rests upon a dome of fire-brick, and the remainder is supported by cast-iron plates, resting upon supports of brickwork, which serve to disseminate the heat of the furnace under the bottom of the pan.

In Fig. 12, A shows the fire-bars of the furnace, and C the course of the flame, interrupted repeatedly by the upright brick walls, serving the double purpose of equalizing the heat under the pan, and of supporting the iron plates on which it is laid.

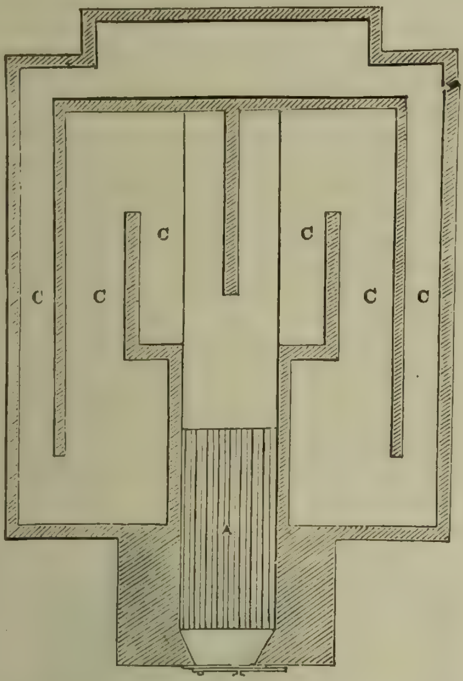
The impurities which pass off in large quantities from the distillation of the bones are condensed in the liquid, and are almost entirely separated in the tank on the addition of the acids. Before evaporation, it is found necessary to remove them completely, which is most conveniently done by a process of filtration. The filters consist of a long wooden box lined with sheet-lead, and having an outlet pipe at its lowest end, for the purpose of drawing off the liquid into the receiver. A frame, corresponding to the shape of the vessel, is adjusted by means of wedges, perfectly horizontal, and within 1 inch of its bottom. Round bars of wood are fixed lengthways in this frame, and upon it a canvass or stout linen cloth is drawn tightly, being secured at the sides and ends of the frame by means of tacks. On passing the liquid through this cloth, most of the solid impurities are retained; and in order that there may be as few of these as possible in the liquid, it is returned by means of a pump from the tank two or three times, to undergo fresh filtrations. A common receiver, placed below the others, may be made to communicate with any of the filters by means of intermediate stopcocks.

Fig. 11.



When the liquid is sufficiently clear, it is pumped up into the evaporating pans just described, and concentrated. As soon as the liquid acquires a certain gravity, it is drawn off to the crystallizing pans These are wooden boxes lined with sheet-lead, and are of various dimensions, from 6 to 10 feet in length, 3 to 6 feet in breadth, and 1½ to 3 in depth. When the mass of salt is crystallized, the crystallizers are inclined towards either side, in order to drain off all the mother liquor, which is received in a suitable cistern, and is afterwards pumped into the evaporating pans, to be concentrated with another portion of the ammoniacal liquor; the pump employed is made of lead, hardened with antimony and tin.

Fig. 12.



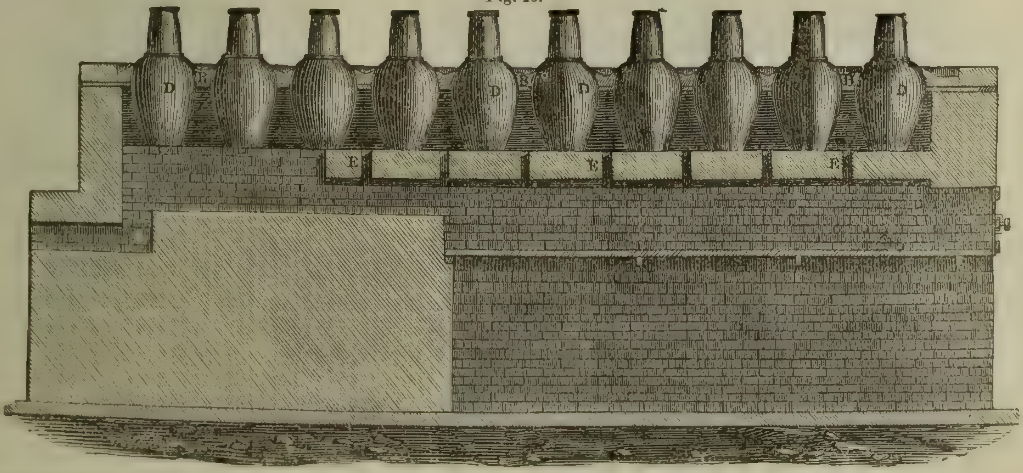
When the crystallized chloride of ammonium is well drained, it is submitted to the subliming process. The arrangement used for this purpose is represented in the annexed woodcuts, Figs. 13 and 14.

The sublimers are earthen or stoneware pots, placed in two ranks, upon the arch of the flue, passing from the fire, A, which heats them. The longitudinal section of the furnace—Fig. 13—shows one row of these pots. Under the pots, represented in the engraving by D, circular openings from the main flue are made in the arch of brickwork, by which the heated vapour and flame are made to circulate around them, and thus they become hot enough to sublime the salt. The bottles, or pots, are encased in the furnace as far as their necks, as seen in the front view and transverse section in Fig. 14; and a plate of iron, with indentations corresponding to the size of the bottles, runs along between the two lines, as shown at B B. The space between this plate and the dome on which the bottles rest is left for the free circulation of the flame and heated air of the furnace, which effects the sublimation. To economize fuel, an evaporating pan is often appended to the subliming furnace; the heated air from the chamber of sublimation is in this case, as it passes to the chimney, made to run along a number of square openings, over which the evaporating pan is supported by cast-iron plates, and at the end of this pan they unite into one flue, just before entering the chimney.

The salt is generally dried in this manner previous to being sublimed.

The pots are of variable dimensions, but those most frequently employed are about 18 inches in height in the body, the caps being about 10 or 12 inches, their breadth is 16 inches at the widest part. The annexed numbers show the produce of a large French manufactory of ammonia and its salts, from the distillation of bones and other matters. The materials were—

Fig. 13.



46,754	tons	of bones of various kinds,
30	"	silk waste and old leather,
11½	"	sulphuric acid,
80	"	chloride of sodium, and
2¾	"	sulphate of lime;

and the produce—

2400	tons	of animal charcoal,
44	"	chloride of ammonium,
100	"	sulphate of soda,
4	"	liquor ammonia, and
25	"	sulphate of ammonia.

In this manufactory the sulphate of ammonia is obtained by treating the ammoniacal liquor—which contains chiefly carbonate of ammonia—with sulphate of lime, when double decomposition takes place, carbonate of lime and sulphate of ammonia being formed. The latter remains in solution, and may be obtained by filtration from the lime precipitate, and subsequent evaporation of the solution in the manner indicated by the preceding sketches of the apparatus employed.

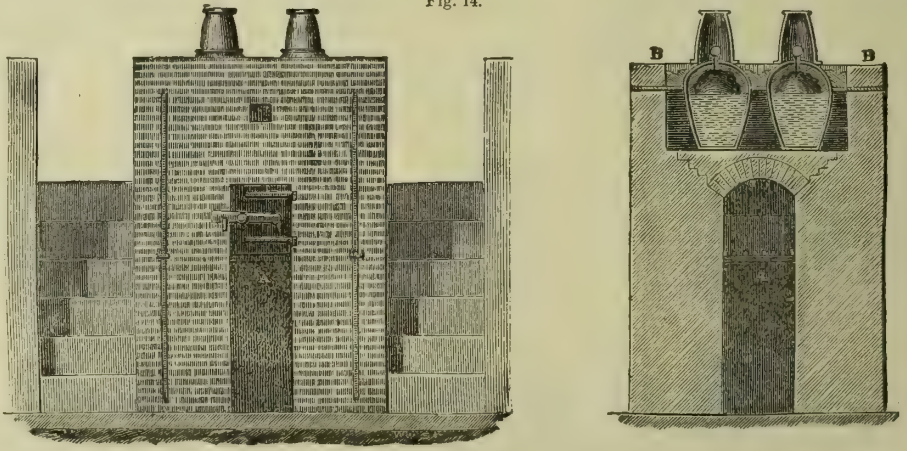
The chloride is prepared either by adding the hydrochloric acid at once to the crude liquor, and evaporating it, or by converting the ammonia into the sulphate, and decomposing this salt by sodium chloride, forming sodium sulphate and ammonium chloride; the latter is separated by sublimation. Occasionally, manganese chloride, from the refuse liquor of chlorine stills, is used to decompose the crude ammonium carbonate; manganese carbonate precipitates, and is separated by filtration, and the solution of the ammonia salt is treated as in the other instances.

When offal is used to produce ammonia by destructive distillation, it should not be heated beyond the temperature required to disengage the ammoniacal compounds, as the residual charcoal can then be made available for the manufacture of prussian blue. According to Ure, the density of the liquor from the distillation of the bones and other substances, when mixed, is 1·060 sp. gr.

When ammonium chloride is prepared by means of sulphate of lime and common salt, the following is the method pursued:—

The crude carbonate of ammonia is decomposed by passing it through a bed of sulphate of lime, 3 or 4 inches thick, which is spread out upon filters. The liquor may be poured upon the gypsum by means of a pump. It should never stand higher than from 1 to 2 inches above the surface of the coarsely ground sulphate of lime, and to prevent the dissipation of any of the ammonia, the vessel should be closely covered over with boards. When the liquor has passed through the first filter, it must be pumped upon the second; or the filters being in a terrace form, the liquor from the first may flow down upon the second, thence upon a third, and so on in succession. The last filter should be nearly fresh gypsum, so as to insure the thorough conversion of the carbonate into sulphate. The resulting layers of carbonate of lime should be washed with a little water, in order to extract the whole of the sulphate of ammonia.

Fig. 14.



The ammoniacal liquor thus obtained must be completely saturated, by adding the requisite quantity of sulphuric acid; even a slight excess of the acid can do no harm. It is then evaporated, and the oil, which is generally carried off in the ammoniacal liquor in combination with the alkali, and is set free by the slight excess of acid, must be skimmed off in the course of the concentration. When the solution of ammonium sulphate has acquired the density of 1·160, sodium chloride is added with constant stirring, until the whole quantity required for the double decomposition is introduced into the boiler. The crude liquor must now be drawn off by a siphon into a somewhat deep reservoir, where the impurities are allowed to subside; it is then evaporated by boiling, till the sodium sulphate falls down in granular crystals, being the result of the mutual action of the ammonium sulphate and sodium chloride, thus:—

$$\overset{\text{Ammonium Sulphate.}}{(NH_4)_2SO_4} + \overset{\text{Sodium Chloride.}}{2NaCl} = \overset{\text{Ammonium Chloride.}}{2NH_4Cl} + \overset{\text{Sodium Sulphate.}}{Na_2SO_4}.$$

while the ammonium chloride, being more soluble, remains in the liquid. During the precipitation of the crystallized sulphate of soda, the whole of the liquid must be agitated by wooden paddles or spatulas, the precipitate being in the intervals removed to the colder part of the pan; thence it is taken by means of copper rakes and shovels, and thrown upon the draining copper placed near the edges of the pan. The drained sodium sulphate must be afterwards washed with a little cold water, to extract all the adhering ammonium chloride. The liquor thus freed from the greater part of the sulphate, when sufficiently concentrated, is to be drawn off by a leaden siphon into the crystallizers, where, at the end of twenty or thirty hours, it affords an abundant crop of crystals of ammonium chloride. The mother liquor may then be run off from the crystallizers, which should be placed in an oblique position to drain the salt; when this is done, the crystals must be washed, first with a weak solution of chloride of ammonium, and next with a small quantity of water. The mass of crystals is then desiccated in a furnace, where all the moisture is removed, after which it is put into the earthen subliming bottles by means of a funnel, and rammed down tightly; the heads are then placed securely on, and heat cautiously applied, so as to effect the sublimation of the pure salt from the bottom to the upper part of the bottle. The vent hole, as shown in the section of the bottles in Fig. 14, must be cleared from time to time, by means of a long steel skewer, to prevent the risk of choking, and consequent bursting; in spite of these precautions, however, several of the bottles are generally cracked in almost every operation.

The preceding method of sublimation is not often adopted in the manufactories of ammoniacal salts in this country. A process somewhat analogous is pursued in Glasgow, where the salt is expelled from cast-iron pots lined with fire-proof tiles; the vapours are received and condensed in a hollow globular head of green glass, with which each of the iron pots is capped. The chloride of ammonium thus formed is sold in hollow spherical masses, corresponding in shape to the head of the vessel, being previously freed from any adhering impurities by mechanical means. The residuary matter left in the pots, which still retains some of the salt, is lixiviated, and the liquor worked up in another operation.

Ammoniacal salts are now more extensively produced from the crude liquor of gas-works than from any other source; this entirely dispenses with the disagreeable necessity of collecting and storing putrid urine for the purpose—a practice formerly extensively followed.

In a large Glasgow factory, where upwards of 70,000 gallons of gas liquor are consumed weekly, it undergoes the following treatment:—The liquor s first rectified by distillation from a waggon-shaped wrought-iron boiler, into a square cistern of iron lined with lead: 4500 lbs. of sulphuric acid, of specific gravity 1·625, are then added slowly to the somewhat concentrated distilled ammoniacal water. The produce is about 2400 gallons of solution of sulphate of ammonia, slightly acidulated, of spec. grav. 1·150, being of such strength as to deposit a few crystals upon the sides of the leaden-lined iron tank in which the saline combination is made. This liquid is decomposed with common salt to obtain the chloride.

The following routine is practised at the factory of Messrs. KURTZ, CROPPER, & Co., in Liverpool. The gas-works supplying the crude liquor are situated on each side of the factory, at the distance of three-quarters of a mile; a communication is opened by means of a canal, on the banks of which are the two establishments. Flats, constructed of sheet iron, and divided into compartments of known capacity, convey the ammoniacal liquor to the factory. As soon as the flat comes alongside, the gas liquor is drawn off by a hose, 8 or 10 yards long, to a receiver placed within the walls of the premises; thence it flows through a conduit pipe to large subterranean cisterns, capable of holding 100,000 gallons or more, which are situated nearly in the middle of the factory, and adjacent to large tuns, each capable of holding 14 to 18,000 gallons. Fig. 15 shows the front of these tuns, and the general apparatus appended to them.

By means of a pump, A, connected with the reservoirs, the crude liquor is raised into the tuns; and after a considerable quantity has been pumped, strong hydrochloric acid, in the proportion of 1½ or 2 lbs. to the gallon of the crude liquor, is introduced by the aid of a pulley, or crane, and gutta percha carboys, as shown in the engraving. Metallic pumps cannot be used, on account of the corrosive action of the acid, and even pumps made of gutta percha do not answer.

When the proper quantity of acid has been added, both liquors are intimately mixed by an agitator placed within the tuns, and worked by the same machinery as the pump in connection with the subterranean reservoir; this machinery, however, is not seen in the figure. Disagreeable vapours, consisting of sulphuretted hydrogen and other injurious gases, are disengaged in large quantity during the saturation of the liquid; these are not permitted to escape into the atmosphere, but are made to traverse the fire belonging to the steam engine, being conducted thither by the pipes, D D.

The liquor in the tun should have a faint but distinct acid reaction. The hydrochloric acid, besides uniting with the ammonia, causes the tar and other bodies, held mechanically and in solution, to separate and subside to the bottom of the tun in the course of three or four days, leaving the supernatant liquor much purer, but still deeply coloured.

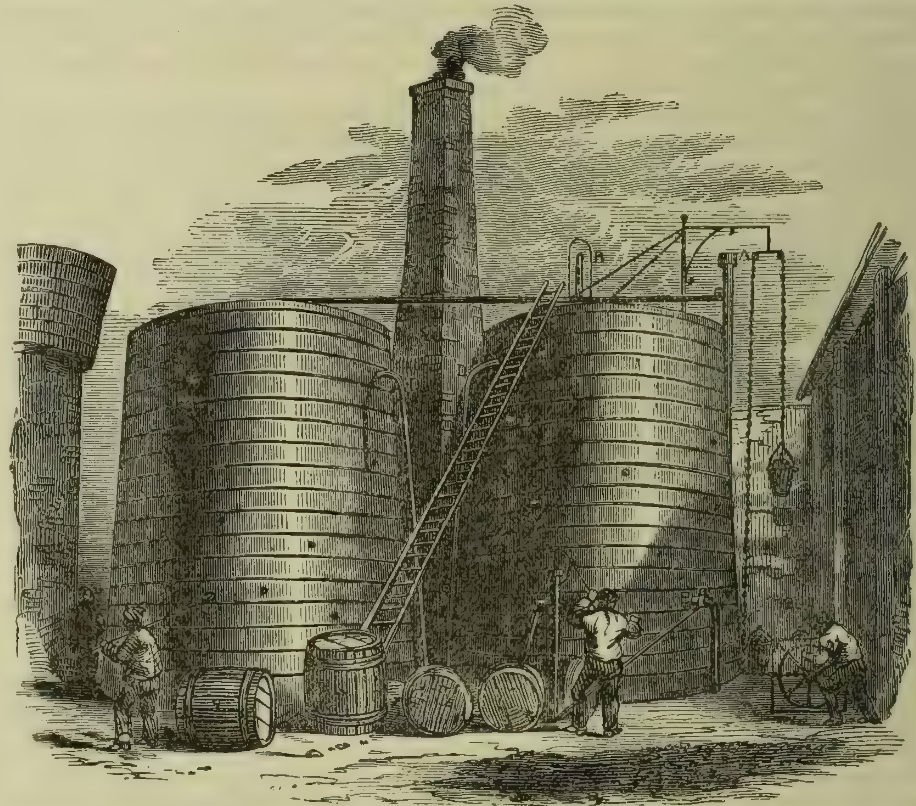
The liquor is drawn off at several outlets, shown by the dots in the sides of the tuns, but which are kept plugged during the previous part of the operation, and conducted by small sluices or troughs to the store vats and the several concentrating pans, all of which are constructed of iron plates riveted together. The deposits of tar and other matters are drawn off at the lower openings, or by the tap in the pipe, E, when they have accumulated to that elevation (though this rarely happens), to a reservoir adjoining, whence they are pumped into barrels, to be carried to another department of the factory. When there is a superabundance of crude ammoniacal liquor, it is conducted by the pipe, E, to the sulphate of ammonia works of the establishment.

The evaporators are square, rectangular, or circular iron vats, capable of holding from 800 to 1500 gallons; some of them are partly incased in brickwork. Heat is usually applied by a fire, the flue of which takes a sinuous course beneath the lining of brickwork on which the pan rests. During the concentration considerable quantities of petroleum and other impurities, not deposited in the tun, separate, and are immediately removed by skimming. The liquor, which marked only 5° Twaddle previous to being submitted to the action of heat in the pans, is of 50° Twaddle, or 1·25 specific gravity, when transferred to the crystallizers. The solution is slightly acid when drawn over from the mixing tun, and this acidity becomes more distinct as the excess of water is dissipated, and might be productive of inconvenience if it were not neutralized from time to time by the addition of quicklime or chalk in small quantities, or by saturating it with ammoniacal liquor. The neutralization also precipitates any sesquioxide of iron present, and which might prove mischievous in subsequent operations. The liquid being brought to the gravity 1·25, as above noted, is run off to the crystallizers, which are for the most part circular tubs, from 7 to 8 feet in diameter, and 2 to 3 in depth; they are partly imbedded in, or rest upon, the ground.

Fig. 16 is a view of a range of these vessels; they are so placed that the concentrated solution of the chloride of ammonium can be drawn into them from the boilers.

The salt crystallizes out in from four or six days, according to the state of the weather. In crystallizing ammonium chloride, it is not desirable to have large and well-defined crystals, especially when the salt is to be afterwards sublimed; since the process is much more difficult with such crystals, on account of their cohesiveness, than with the more divided salt. On the contrary, when small crystals are submitted to the heat, the cohesion offers scarcely any resistance, a greater surface being exposed, so that the sublimation proceeds rapidly. Hence, when the solution of the salt is set to solidify, the crystals which form on the top, as well as those on the sides and bottom of the vessels, are broken by agitating the liquor every six or eight hours, according to its state of concentration. Eight or ten days are allowed for the salt to crystallize, after which the mother liquor is removed through an opening at the bottom, to a well sunk in the ground, whence it is again pumped into the concentrating pans as shown in the engraving.

Fig. 15.

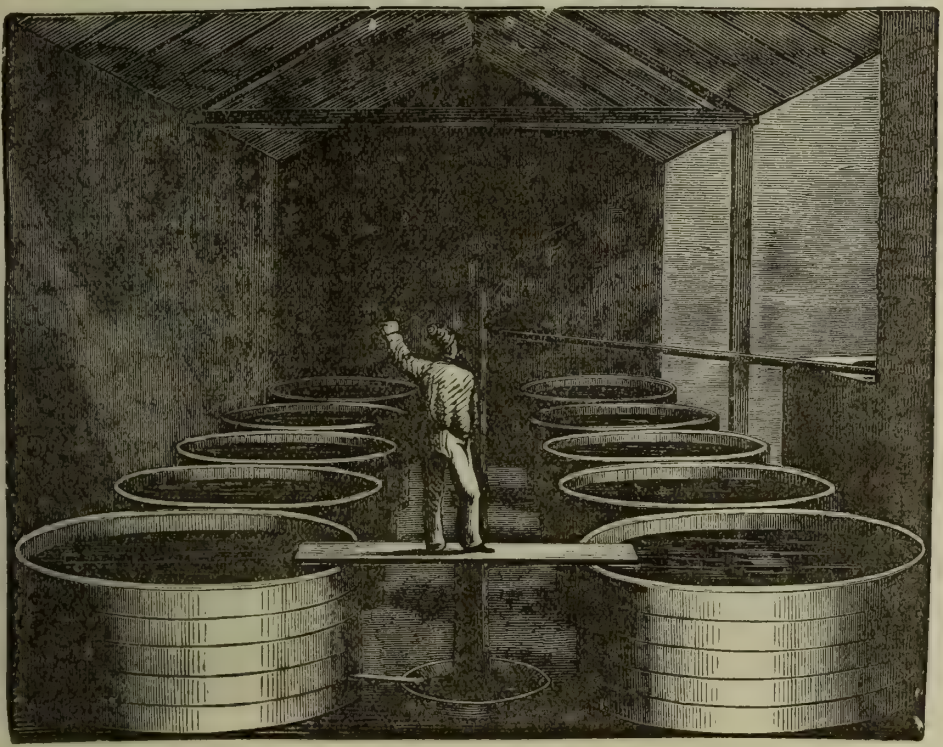


Ammonium chloride, as obtained by the first crystallization, is a blackish salt, interspersed with moderately large cubical crystals. The blackness arises from tarry, oleaginous, and other impurities, mechanically held in the liquor, which fall down, more or less, with the crystals; the chloride also contains sulphates and hyposulphites and water, these all tend to deteriorate the quality of the ammonium chloride, if not removed before sublimation. To get rid of the impurities, the well-drained crystals are introduced into the bed of a drying furnace, covered with a cast-iron plate, the whole surmounted with a dome of brickwork, and erected near the sublimers. This drying bed is heated by a fire placed under it, the flue of which is brought several times into such a position that the plate is within its influence. This chamber is between 6 and 8 feet in length, and about 4 feet in breadth, and a sufficient charge is introduced to cover the entire plate to the depth of 4 inches. The heat should never be raised very high, lest some of the salt be volatilized. When all the water and free acids are removed, and the empyreumatic impurities for the most part decomposed, the greyish-white mass is drawn out and taken to the subliming apparatus, where the salt is eliminated from the non-volatile impurities.

The sublimers are circular spaces, constructed in a mound of brickwork, walled interiorly with fire-brick, and lined with cast-iron plates, round the sides of which the flue from the fire underneath coils, after it passes from the bottom. The subliming vessels are capped by an iron cover, somewhat of the shape of a flat-bottomed watch-glass. They are from 3 to 9 feet in diameter, and their concavities about 2; they weigh from 10 to 30 cwts. Three rings, at equal distances, allow of their being lifted off by means of a pulley and chains which can be attached to these rings. When in active operation a pressure of from 3 to 4 lbs. per square inch bears against them, which requires their being firmly fixed to the flat rim of the body of the subliming vessel. In the centre of some of these is a small hole, closed by an iron spindle, which is removed from time to time, to allow any elastic uncondensable products to escape.

The annexed woodcut, Fig. 17, is a view of the sublimers and drying furnaces. They are heated by the fires, which are briskly kept up till the sublimers and their surroundings attain a sufficient degree of heat; they are then slackened, and maintained at an even temperature till the operation is completed.

Fig. 16.



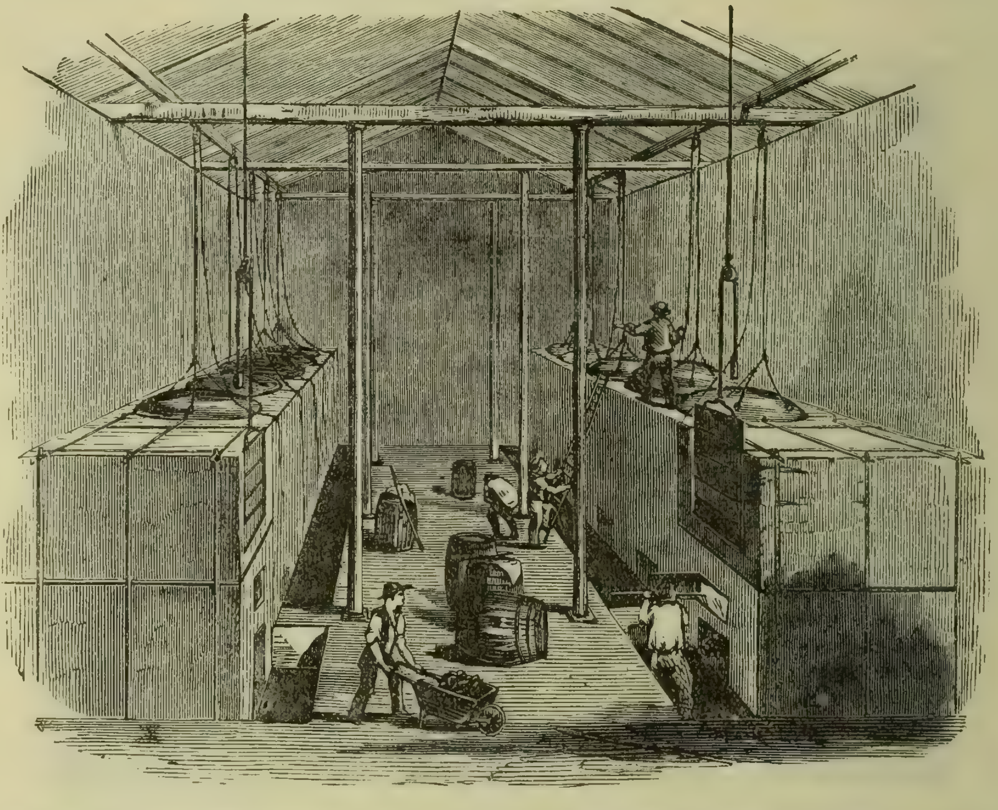
Much of the success of the sublimation depends upon the regulation of the heat. If the temperature is too high large quantities of empyreumatic bodies are disengaged, which interfere with the operation by preventing the solidification of the salt; and should the temperature be too low, there will be a looseness of texture and an opacity in the salt which greatly deteriorates its value in the market. The top of the sublimer is invariably covered with some non-conducting material, that the heat may be economized as much as possible.

As the size of the sublimers varies, as above stated, so also does the amount of the charges, being from ½ to 2 or 2½ tons weight of the salt; the former is sufficient for sublimers of 3 feet diameter, and the latter for those which are 9 feet; sublimers of 5 feet diameter generally require from 15 to 18 cwts. of the salt.

In consequence of ammonium chloride retaining some traces of water, even after passing through the drying furnace, and as it always absorbs a little from the atmosphere while the workmen are transferring it to the sublimers, the first coating of the salt in contact with the cover is always brownish. Several reasons may be assigned for this effect: firstly, the moisture condensing upon the head, and softening any small quantity of ferric oxide present, would cause it to sink into the layer of salt that deposits thereon; secondly, decomposition of any resinous matters not completely destroyed in the drying furnace, whereby oily vapours would be liberated; and lastly, the accidental presence of ferrous or ferric chloride. The effect of the latter, however, is not generally on the first layer, but more frequently afterwards, when the temperature is higher.

The termination of the sublimation takes place in from five to nine days; but it is customary to raise the caps every week, the fire being checked for some hours previously. The salts are not sublimed to their last dregs, because the temperature required would cause the decomposition of the carbonaceous impurities, and emit vapours which would destroy in a great measure the beauty of the sal-ammoniac. When a low temperature is used, or the compound consigned to the subliming furnace is impure, the chloride does not assume that compactness of grain which conduces to its transparency, but forms a kind of effloresced mass, though retaining the fibrous construction of the better quality.

Fig. 17.



When the sublimation has reached as far as is desirable, the fire is allowed to go out that the apparatus may cool; the cover is then removed by means of the tackle before noted, and there is found in the interior a hard lining of the salt, from 2½ to 3 or 4 inches thick; this is detached and conveyed to the packing-house or store, and the residuary matter remaining in the body of the sublimers is removed to another part of the factory to be converted into sulphate of ammonia. The brown coating, arising from the causes before alluded to, is separated from the cake by means of axes. The greater part of the chloride of ammonium manufactured is employed by colour-makers and calico-printers, and by makers of galvanized iron.

Sulphate of Ammonia.—*Ammonium sulphate, sal-ammoniacum secretum,* Glauber; $(NH_4)_2SO_4$.—This salt forms crystals resembling those of potassium sulphate, with which it is isomorphous. They belong to the trimetric, *i.e.*, the right prismatic system. The prisms have six faces, and terminate in six-faced pyramids, belonging to the orthorhombic type.

Ammonium sulphate is colourless, has a sharp bitter taste, and is soluble in its own weight of boiling water, or twice its weight of cold water. In alcohol it is wholly insoluble. When heated it decrepitates, and at 284° Fahr. (140° C.) melts. Above 536° Fahr. (280° C.), it is decomposed into ammonia, nitrogen, water, and acid ammonium sulphite, which latter sublimes. When a solution of ammonium sulphate is subjected to protracted boiling, it is in like manner split up. At a dull red heat it is completely decomposed, and yields sulphur, nitrogen, and water thus:—

$$\begin{array}{ccccccc} \text{Ammonium sulphate.} & & \text{Sulphur.} & & \text{Nitrogen.} & & \text{Water.} \\ (NH_4)_2SO & = & S & + & 2N & + & 4H_2O. \end{array}$$

Ammonium sulphate is found native (Mascagnite), usually in mealy crusts and stalactitic forms. It collects about the solfatara of Naples, round volcanoes, and in the fissures of the lava, as at Etna, Vesuvius, and the Lipari Isles. This mineral is named after its discoverer, Professor MASCAGNI.

Manufacture.—Sulphate of ammonia is obtained from gas liquor by the following process:—A large pipe conveys a quantity of gas liquor to a large boiler placed over a fire, the flue from which circulates round the bottom and sides; a large pipe issues from its upper surface top, and descends through an adjoining tun, containing sulphuric acid, to its bottom. By bringing the contents of the boiler to ebullition, the free ammonia is driven off through the pipe into the tun containing acid; here it is absorbed by the sulphuric acid, giving rise to ammonium sulphate. Distillation is continued till no more ammoniacal vapours are given off, and then the fire is checked, while the residual liquor is drawn off and mixed with sufficient quicklime to give it a strong alkaline reaction; the whole is then run into a second and larger boiler, like the preceding, on the principle of a still; under this a brisk fire is applied, and the ammoniacal vapours liberated by the action of the lime are transmitted through the sulphuric acid solution in the tun. After all the ammonia is obtained, the waste liquor is run off.

During the time the ammonia vapour is blown through the sulphuric acid liquor, much water is removed from the solution by the heat from the steam and ammoniacal gas, so that less fuel is required in further concentrating the liquor. The evaporating pans are similar to those used for boiling down the chloride of ammonium solution. Much more care is requisite when fire is applied directly to the pans, than when the concentration is effected at a steam heat; for the organic matter which the liquor contains partially decomposes the sulphate into sulphide, which reacts upon the iron pans, or by the excess of acid present is decomposed, giving off sulphurous acid or sulphuretted hydrogen gas. The operative watches carefully for any traces of the odour resembling that of rotten eggs, which characterizes sulphide of hydrogen, because this tells him that decomposition is taking place, and of course admonishes him that it should be prevented by immediately withdrawing or slacking the fire.

Crystallized sulphate of ammonia obtained in the first operation is much purer than the chloride of ammonium already described, in consequence of the impurities of the crude liquor being removed by the distillation. After the crystallization, the crude liquor which is still acid is returned to the tun, to combine with further quantities of ammonia.

Besides the ordinary gas liquor, the impure chloride from the packing-house and the refuse of the sublimers are decomposed by lime, and the eliminated ammonia either transmitted through the acid solution to form sulphate, or used to prepare the carbonate. The sublimation of the crystallized sulphate cannot well be effected; but ammonium chloride may be prepared from it, by mixing it with a proportionate quantity of chloride of sodium, and then heating; the chloride is sublimed, and sulphate of soda remains in the bottom of the sublimer.

In subliming ammoniacal salts, considerable advantage results from the use of large vessels, as the labour of attending them is less in proportion, and the fire which is requisite to heat a pan of 3 feet in diameter would serve, with very little addition, to sublime the contents of one of 9 feet; the time required also in working the charge of each sublimer, whether it be 3, 5, or 9 feet diameter, is nearly the same, though the quantity of salt produced by the larger ones is very different. A great advantage in speed of working is gained by making the bottom rise in the centre instead of being flat. The heat is thus sooner communicated to the mass of the material, and the time required for sublimation is much shortened. Ammoniacal gas liquor yields from $\frac{3}{4}$ lb. to $1\frac{1}{4}$ lb. of sal-ammoniac per gallon of liquor, but this quantity is subject to much variation from many causes.

In the manufacture of ammonium chloride as already described, if the purification of the liquor be not effected before crystallizing the salt, some traces of ferrous chloride are generally present, sometimes in large proportions. When the crystals are submitted to heat in sublimation, the ferrous chloride is volatilized, and blends with the ammoniacal salt in the colourless as well as in the dark or brown seams of the cake.

WURTZ, who examined this substance, states that neither the brown nor colourless portions of the sublimate give any indications of iron with the usual reagents, until nitric acid has been added to convert the ferrous salt into the ferric modification, after which the addition of potassium ferrocyanide produces a very distinct precipitate of Prussian blue, and potassium sulphocyanide a red coloration. It was not generally considered that the colourless chloride of ammonium contained iron till WURTZ discovered this reaction. It seems that the iron might be present in the lie as ferric chloride, and is subsequently converted into ferrous chloride by the reducing action of ammonium chloride. The reaction may be represented as follows:—

$$\overset{\text{Ferric chloride.}}{Fe_2Cl_6} + \overset{\text{Ammonium chloride.}}{2NH_4Cl} = \overset{\text{Ferrous chloride.}}{2FeCl_2} + \overset{\text{Hydrochloric acid.}}{4HCl} + \overset{\text{Amidogen.}}{2NH_2};$$

or—

$$\overset{\text{Ferric chloride.}}{3Fe_2Cl_6} + \overset{\text{Ammonium chloride.}}{2NH_4Cl} = \overset{\text{Ferrous chloride.}}{6FeCl_2} + \overset{\text{Hydrochloric acid.}}{8HCl} + \overset{\text{Nitrogen.}}{2N}.$$

In either case the ferric chloride is converted into ferrous chloride.

Repeated crystallizations would remove the iron compound, but this would cause a loss of time, fuel, and material. The smallest trace of this salt can be separated at very slight cost by passing a few bubbles of chlorine gas through a concentrated hot solution of the salt in the crude state, which reconverts the ferrous chloride into ferric chloride; this in turn is decomposed by free ammonia, with the precipitation of hydrated ferric oxide of iron and the formation of ammonium chloride. The liquor is kept hot for some time, till the whole of the flocculent brownish matter settles to the bottom, after which it is rapidly filtered and set aside to crystallize. By this means a perfectly pure salt, free from the least trace of iron, is obtained. Great care should be taken to keep the solution hot during the time the chlorine is being transmitted through it, and also not to prolong the action, in order to prevent the formation of the well-known dangerously explosive mixture, nitrogen chloride, NCl_3. (This substance is now thought to contain hydrogen, and to be represented by the formula $NHCl_2$ or NH_2Cl).

CROLL gives the following instructions for the preparation of ammoniacal salts:—A vessel, similar to those used for purifying coal gas by means of moistened quicklime, is filled with a solution of manganese chloride, made by dissolving 1 cwt. of that salt in 40 gallons of water, and the gaseous ammonia, generated either by addition of lime to gas liquor and heating, or by driving high pressure steam into the gas liquor to which milk of lime has previously been added, is passed through it by the pressure from the retort. The manganic solution absorbs the ammonia, which precipitates a corresponding proportion of oxide of manganese, and as soon as fully saturated it is drawn off, and a fresh charge introduced.

When sulphuric acid is to be combined with the alkali, a vessel similar to that for washing the gas is used, the sulphuric acid used being of specific gravity 1·845, and in the proportion of 2½ lbs. of acid to 100 gallons of water. The gas is passed into it till the liquid marks a specific gravity of 1·170, when it is drawn off and a second charge supplied.

In preparing chloride of ammonium the hydrochloric acid is taken at a density of 1·165 before diluting it, and then charged with the ammonia gas till the gravity is 1·176; the proportion is the same as with sulphuric acid. In the preceding case of the manganese salt being used, the ammoniacal compounds are purified by filtering off the solution from the precipitated oxide, evaporating the filtrate, and subliming the residue. Sulphate of manganese, or ferrous chloride, may be substituted for the chloride of manganese. That portion of metallic oxide which remains is again converted into a fit state to absorb fresh quantities of the alkaline vapour, by the following simple method:—To every three parts of this residue four of common salt are added, and the mixture heated in a furnace to low redness, which is scarcely perceptible in the dark, for about two hours or longer. Forty gallons of water are then added to every 140 lbs. of this mixture, and the liquid thus produced absorbs ammonia very rapidly. The precipitate which falls, consequent on the retention of the ammonia, only requires to be dissolved in the acid which is intended to form a combination with the alkali, to render it suitable to serve the intended purpose a second and a third time.

HILL proposed to convert the ammonia eliminated in the distillation of coals into chloride, by mixing chloride of manganese with the coals in the retort, or introducing the chloride into a retort appropriated for the purpose; the heat dispels the hydrochloric acid, and this, uniting with the alkaline vapour, forms chloride of ammonium, which is retained in the liquor in the condenser. After removing the tar in the usual way, the salt is obtained by evaporation and sublimation, as before described. This process was not commercially successful.

SPENCE uses a series of cylindrical-covered boilers, or reservoirs, placed at such different elevations that the contents of the uppermost may be drawn off into the next, and so on in succession to the lowest, as an economical arrangement in preparing chloride of ammonium, or sulphate of ammonia, from gas liquor, &c. Each boiler has an exit pipe, which carries the vapour generated in it to that which is next above it, and the exit pipe of the highest boiler passes off to a tank, where the acid requisite to form the salt is supplied. A charging pipe connects the top boiler with the reservoir of gas liquor, which is already mixed with milk of lime, and by turning a stopcock attached to it the boiler may be replenished. Four boilers are deemed sufficient, but a larger number may be used. A pipe conveying high-pressure steam enters the lower boiler, by which the liquid is made to evolve its ammonia into the next boiler; and in the same manner the contents of this and the upper boilers are brought to the temperature of ebullition, the ammonia passing through each by the connecting pipes, till it is expelled from the highest, in a very concentrated state, to the acid tank. When moderately concentrated acid is used after the absorption of the ammonia in the series of boilers, the lie is so strong that it may be drawn off at once to crystallize. As the liquor in the lowest boiler becomes exhausted of its ammonia, the fire is slackened and the contents run off, and that of the next boiler admitted instead; the latter is supplied from the one above it, and so on to the highest, which is filled from the reservoir. When the boilers are replenished the fire is stirred up, and the distillation proceeded with as before. The solution of chloride of ammonium, or sulphate of ammonia, is treated in the usual way for obtaining the dry salt.

Salts of ammonia are prepared from guano by destructive distillation in close iron cylinders. A low red heat is maintained during the greater part of the operation; this temperature is increased towards the end. The eliminated gases are made to pass through vessels arranged on the principle of Woulfe's bottles. Carbonate of ammonia, hydrocyanic acid, and marsh gas, are copiously disengaged; the first two, being rapidly absorbed, give a strong solution of ammonium cyanide and carbonate of ammonia, while the marsh gas passes into the atmosphere.

As soon as the charge of the retorts has been exhausted, the solution in the condensing apparatus is drawn off, and mixed with as much ferrous chloride as is necessary to separate the whole of the hydrocyanic acid in the form of Prussian blue. In consequence of the free ammonia present the precipitate does not at once appear on adding the iron salt, but on neutralizing this ammonia with hydrochloric acid it then falls down of a fine blue colour; this is filtered off and well washed, after which it is converted into potassium ferrocyanide (*yellow prussiate*) by boiling with potassa, evaporating the solution, and crystallizing in the usual way. If an excess of iron is present in the liquid filtered from the iron precipitate, it is separated by adding carefully a fresh quantity of the ammoniacal solution, which precipitates it, and it is then removed, and the neutral solution of ammonium chloride evaporated. Sulphate of ammonia is procured in a similar manner, by employing sulphuric instead of hydrochloric acid, and sulphate of iron instead of the chloride.

Peat is rich in ammonia, and therefore the fabrication of ammoniacal salts from this source have formed a main feature in the multitudinous schemes for its utilization.

According to the statements which have been drawn up by Sir Robert Kane and others, peat yields from 22 to 25 lbs. of ammoniacal salts per ton.

For the preparation of ammonium chloride or sulphate, Laming adapted various compounds to be used in the purifiers of gas-works; and through which the gases given off from the retorts are transmitted, so as to retain the ammoniacal vapour. These substances are ferrous chloride decomposed by hydrate of lime into oxide, with the formation of calcium chloride, ferrous sulphate (which he converts by means of chloride of sodium into ferrous chloride), and sodium sulphate of soda. The chloride thus prepared is then decomposed, as in the preceding instance. Further, he uses a mixture of calcium sulphate and ferrous sulphate, or of the precipitated hydrated ferric oxide with calcium carbonate, magnesia, magnesium carbonate, or magnesian limestone; of magnesium chloride or sulphate and water; of phosphate of lime dissolved in hydrochloric acid; and of a mixture containing magnesium sulphate or chloride in combination with oxide of copper, and mixed or not with lime or magnesia, or both or either, or both of the carbonates of those earths. In all these cases the salts or mixtures employed are mingled with sawdust or some porous substance before being placed in the purifying vessel. After they become saturated with ammonia, the chloride or sulphate formed is removed by simply washing the mass with water.

Laming, later on, employed sulphurous acid to prepare sulphate of ammonia. The ammonia is liberated in the free state or as carbonate, by any simple means, and received in water; by a stream of sulphurous acid gas transmitted through this ammoniacal liquid, it is converted into ammonium sulphite. By agitation and exposure to the air this salt is oxidized, and becomes ammonium sulphate.

Sulphate of ammonia was manufactured by Mitchel by means of sulphate of lead, containing an excess of oxide. On submitting such compounds to the ammoniacal solutions, decomposition of the lead salt takes place, being converted partly into sulphide, and partly into a carbonate, while ammonium sulphate results. He prepared the oxysulphate in the following manner:—Native sulphide of lead is ground into small fragments; the reduced mass is then spread upon the higher of two shelves constructed in a reverberatory furnace, where it is heated for about two hours. It is then drawn off to the under bed or shelf, where it is more strongly heated, and kept occasionally stirred to prevent fusion or caking of the mass, and also to have every part equally heated. The second heating effects the transformation of a portion of the sulphide into sulphate, while another part is oxidized and sulphur eliminated. The layer of galena is about 2 to 2½ inches in depth.

Wilson obtained sulphate of ammonia from the waste products of coke ovens, &c., by transmitting the vapours through a circular tower filled with coke. A cistern at the base of the tower is filled with sulphuric acid, so much diluted that, when completely saturated with ammonia, the heat of the apparatus will not concentrate it sufficiently to deposit crystals of the salt. Another cistern, similar to the preceding, is placed on the top of the tower, the bottom of which is perforated. All the vapours from the ovens are forced through the lower cistern and up the tower; and by an arrangement which continually raises the dilute acid liquor of the lower tank to the upper, so that it again falls through the perforations, any of the alkali that may escape combination from the cistern is taken up by the trickling solution in the body of the cylinder.

The sulphate of ammonia is obtained from the solution after the acid employed has been neutralized, by filtration, evaporation, and crystallization.

Dr. Richardson proposed to obtain ammonium sulphate by forming a double sulphate of magnesium and ammonium, and then submitting this product to sublimation.

Sesquicarbonate of Ammonia.—*Ammonium sesquicarbonate*, *half acid carbonate*, *tetramonio-dihydric carbonate*, *sal-volatile*, *salt of hartshorn*, &c.; $N_4H_{18}C_3O_9 = (NH_4)_4H_2(CO_3)_3$.—Commercial sesquicarbonate, or carbonate of ammonia, consists of half-acid carbonate more or less mixed with other ammonium salts. This compound is prepared on the large scale by the dry distillation of bones and other animal matter; or by heating ammonium chloride or sulphate together with chalk to redness, in close vessels; double decomposition of the two compounds follows, causing the formation of sesquicarbonate of ammonia, and a lime salt analogous to the ammoniacal one taken.

Leaden chambers are used as condensers to retain the volatilized salt from the heated retorts; they generally have the top or bottom partly movable, or have a door in their sides to allow of the removal of the salt. The crude sesquicarbonate obtained in the first sublimation is purified by expelling it by heat from iron pots surmounted by leaden caps. The waste heat of the flue from the furnace which heats the retorts serves for this part of the work. In the second operation water is added to render the salt translucent.

The annexed woodcut, Fig. 18, represents such an arrangement as is here mentioned. In this figure the retorts are cylindrical, and laid horizontally in the furnace, similar to those used in the carbonization of wood for the production of wood vinegar, having the exit pipe for the passage of the sublimed salt at the back; or they may be like those already described in the distillation of bones.

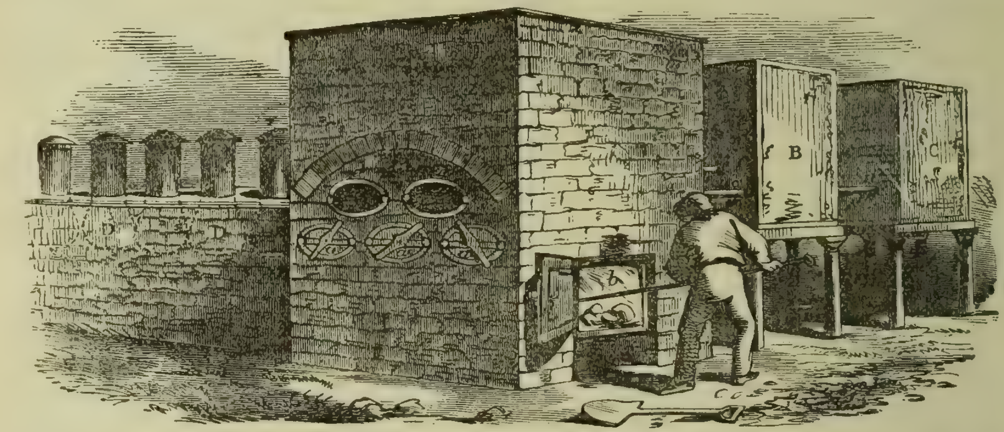
A is the exterior of the furnace containing the five retorts, *a a a a a*, laid horizontally, and closed at the front by iron doors made secure by bolts and screws. Heat is communicated by the fire, *b*, at the end of the furnace. The pipes, *c c*, carry off the vapours of ammonium carbonate into the chamber, B, and whatever remains uncondensed in this is discharged into a second one, C, by the connecting pipe, *d*. Both chambers are supported upon pillars or scaffolding, to bring them on a line with the retorts; D D are the purifying pots, made of cast iron, and surmounted with leaden heads, into which the carbonate is volatilized from any fixed impurities by the heat of the flue from the fire, *b*.

One part of ammonium sulphate or chloride, mixed with 1½ or 2 parts of carbonate of lime, is introduced into the retorts, and a moderate heat applied at first, which is gradually increased towards the end of the operation. The vapours which are eliminated through the pipes, *c c*, in the figure, are condensed in the chambers, B and C. After the charge in the retorts becomes exhausted, the salt condensed in the chambers is removed to the purifying vessels, D D, where it is sublimed at a low degree of heat; sometimes 150° Fahr. (65°·5 C.), communicated by a water-bath, is found to answer the purpose.

Laming recommends, for the preparation of commercial carbonate of ammonia, the conveyance of the constituent gases into a series of large leaden chambers, the temperature of which should be kept as low as practicable, in order to induce as much as possible the combination of those gases. It is unnecessary to have them in combining volumes; in fact, it is desirable that the carbonic acid should be in excess.

A stratum of water, or of a solution of ammonia, is supplied in one or other of the chambers, and in this case the resulting product contains more carbonic acid than when the gases unite as they issue from the vessels where they are generated.

Fig. 18.



The solution is evaporated, and the salt purified by sublimation.

Carbonate of ammonia may be prepared from the ammonium sulphide found in gas liquor by the annexed process. Oxide of copper and charcoal are mixed in the proportion of 12 parts of the former to 1 of the latter; and this mixture is introduced into any suitable retort—cast iron—wherein it is heated to redness; the pipe joining the beak passes through cold water previous to its entrance into the ammoniacal solution of the sulphide or the gas liquor. The action of the heat upon the oxide of copper and charcoal gives rise to carbonic acid, which, entering into the solution, displaces the sulphur in combination with the ammonium, and causes it to be dispersed as sulphuretted hydrogen, while the carbonic acid takes its place, and a solution of carbonate of the alkali is formed.

When the carbonic acid ceases to be given off, the whole of the oxide is found to be reduced to finely-divided metallic copper, and very little, if any, charcoal remains. The retort is cooled, and the contents drawn out, while another retort, similarly charged, maintains the stream of carbonic acid through the solution. During the cooling of the contents of the first retort, the finely-divided copper, by uniting with oxygen from the atmosphere, is reconverted into protoxide, which may be used over again with a fresh portion of charcoal; and so on till the evolution of sulphuretted hydrogen ceases, at which period the liquor is known to be saturated with the carbonic acid gas.

Sesquicarbonate of ammonia is a white fibrous substance, generally found in the market in white translucent cakes of about 2 inches in thickness. It is soluble in 4 parts of water at 55° Fahr., in 3·3 parts at 62°, in 2·7 at 90°, in 2·4 at 105°, and in 2 parts at 120°.

On exposing this solution to moist air, water is absorbed, decomposition takes place, and it is converted into the neutral carbonate and bicarbonate, or acid carbonate of ammonia.

$$\overset{\text{Ammonium sesquicarbonate.}}{(NH_4)_4H_2(CO_3)_3H_2O} = \overset{\text{Ammonium neutral carbonate.}}{(NH_4)_2CO_3H_2O} + \overset{\text{Ammonium bicarbonate.}}{2(NH_4)HCO_3}$$

But the neutral carbonate is very unstable, and speedily resolves itself into the more stable ammonium bicarbonate, at the same time giving off water and ammonia thus:—

$$\overset{\text{Ammonium neutral carbonate.}}{(NH_4)_2CO_3,H_2O} = \overset{\text{Ammonia.}}{NH_3} + \overset{\text{Water.}}{H_2O} + \overset{\text{Ammonium bicarbonate.}}{(NH_4)HCO_3}$$

The same change takes place when solid sesquicarbonate of ammonia is exposed to the air; hence the use of ammonium sesquicarbonate as smelling salts. Bicarbonate of ammonia, remaining after the exposure of the sesquicarbonate, is not so pungent as the salt which produces it. Medically, it is known as mild carbonate of ammonia. It yields a precipitate with bichloride of platinum in the presence of hydrochloric acid; with copper salts it gives the characteristic blue colour produced by ammonia; with the salts of the alkaline earths it does not yield an immediate precipitate; on boiling the mixture, however, the insoluble earthy carbonate falls down.

ROSÉ states that the composition of the sesquicarbonate varies with the mode of preparing it. When obtained by the sublimation of the salt from chloride of ammonium—or any other compound of ammonia—and carbonate of lime, the product is a sesquisalt; but on subsequent sublimation, for the purpose of purifying, he says that it is only four-fifths sesquicarbonate, as his analysis indicates. Sesquicarbonate of ammonia possesses a pungent odour, a hot and saline taste, and a powerful alkaline reaction. The aqueous solution of this salt is used in medicine as a stimulant, and is a useful source of other ammoniacal salts. Bicarbonate of ammonia crystallizes from the hot concentrated solutions of the sesquicarbonate, or it may be precipitated by alcohol. By the action of heat the sesquicarbonate decomposes into various ammonium compounds, containing more or less carbonic acid; the sesquicarbonate of commerce is a mixture of several of these.

Pure ammonium sesquicarbonate is obtained by dissolving the commercial salt in strong ammonia, at about 86° Fahr. (30° C.), and allowing the solution to crystallize. It then forms transparent right-rectangular prisms, with the faces of the corresponding rhombic octahedron resting on the angles. The impurities of the commercial sesquicarbonate are organic matter and small portions of the salt from which it is prepared, which pass over to the chambers unchanged; sometimes it contains hyposulphite of ammonia from the decomposition of the sulphate of ammonia, when this salt has been used, and also traces of lead, derived from the leaden chambers.

Organic matter is detected by simply dissolving the impure article in water, when a solution of a brownish or even blackish colour is produced, while the pure salt affords a colourless liquid. Sulphates or chlorides are detected by dissolving the salt in water, adding a few drops of nitric acid, and dividing the solution into two portions; to one part chloride of barium is to be added, and to the other a few drops of nitrate of silver solution; a white precipitate in these shows the presence of sulphuric acid in the former, and of hydrochloric acid in the latter.

Hyposulphites are detected by neutralizing a portion of the salt with acetic acid, and adding nitrate of silver; a precipitate is obtained, which is white at first, but soon turns black, in consequence of the oxide of silver being reduced. Lead is detected by transmitting a stream of sulphuretted hydrogen gas through a solution of the salt, which occasions a black precipitate if lead be present.

Commercial carbonate of ammonia is used for cleansing woollen cloths, for the extraction of grease in the manufacture of most fabrics; and when free from organic and mechanical impurities it is used in the preparation of yeast and baking powders.

In agriculture, the salts of ammonia are most valuable, increasing in a remarkable manner the fertility of the land, provided the other constituents peculiar to the crop be present; hence they are to be found in all good manures, the value of which they greatly enhance. Ammonia constitutes one-fifth of the weight of genuine Peruvian guano; stable manure also contains ammonia in large quantities, and it is one of the valuable constituents of bone manure. Ammoniacal salts are extensively used in calico-printing, in the preparation of leather, and in pewtering; for the last process, as well as for tinning sheet-iron and iron vessels, the chloride is preferred; on account of its volatility, it substitutes an ammoniacal atmosphere for the ordinary air, and thus prevents the oxidation of the tin.

ESTIMATION OF AMMONIA.—To the manufacturer who employs ammoniacal salts it is very necessary that he should be able to ascertain their real value, and what amount of work he can perform with their aid. The mode commonly adopted is the determination of the amount of alkali with a standard acid. The salt may likewise be distilled with potash through a LIEBIG'S condenser into a flask containing standard acid coloured with a few drops of litmus tincture. The tube from the receiver should not dip into the acid. An U tube containing dilute standard acid up to the bend should be connected with the flask to prevent any loss of ammonia. The liquid is to be kept boiling gently until the drops, as they fall into the acid, cease to render the acid with which they first come in contact blue. The contents of the flask and U tube are then mixed together, and titrated with a standard alkali. The amount of acid which has been neutralized by the ammonia is thus ascertained.

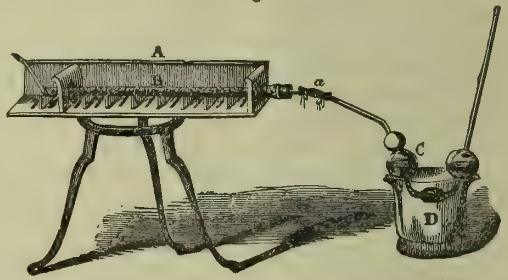
Estimation as Chloride.—In pure solutions of ammonia, or any of its combinations with a feeble volatile acid, the alkali is readily determined by saturating with hydrochloric acid, and evaporating the solution to dryness in a water-bath, till the whole of the free acid and moisture are removed; the dry residue, accurately weighed, gives the amount in the form of ammonium chloride. Should the solution contain only ammonium chloride, evaporation of the water and weighing of the dry residue will give at once the amount of that salt, and the ammonia contained therein may then be calculated. A certain portion of the ammoniacal liquid or solid is weighed, the former in a crucible or covered watch-glass, and the latter in a perfectly clean and dry beaker-glass; these should be rather small, and tared accurately. The solid is then dissolved in water. The succeeding treatment is the same for both. Hydrochloric acid is added in very slight excess, and the solution evaporated carefully, so as to avoid spirting. The evaporation is best conducted in a platinum dish, and when no further loss in weight is sustained by heating in the water-bath, the dish and dry residue are weighed; the difference between this weight and that of the dish is the weight of the chloride of ammonium. If a platinum vessel be not at hand, the evaporation may be continued to dryness in the beaker-glass wherein the solution was originally taken, provided it be small, and the beaker and its contents weighed, as in the foregoing instance; but if this should not happen, when the greater part of the water has been driven off the concentrated liquor is to be carefully transferred to a platinum crucible, or small thin porcelain dish, and also the washings are to be gradually added, the solution evaporated to dryness, and the perfectly dry mass weighed. When the weight of the vessel is deducted from the combined weight, the difference is, as before, the chloride of ammonium. Very accurate results are in this way arrived at, if ordinary care has been exercised, as the trace of chloride which escapes during the evaporation is almost imperceptible. With a similar degree of accuracy, the ammonia may be determined by substituting sulphuric acid for the hydrochloric, and proceeding as above; the ammonia is calculated from the weight of the sulphate.

Estimation as Ammonium Platino-chloride, $(NH_4Cl)_2$, $PtCl_4$. — All those salts of ammonia which are soluble in alcohol may be determined in this form. By converting them into a chloride by the addition of an excess of hydrochloric acid, and evaporating to dryness; then, on dissolving the dry mass in a small quantity of water, and precipitating by a solution of platinic chloride (platinum tetrachloride ($PtCl_4$)) in excess, a yellow crystalline deposit forms, which is the compound salt. The solution is carefully evaporated to dryness at 212° Fahr. (100° C.), the dry mass treated with a little alcohol, and then thrown upon a filter, where it is washed with alcohol till the filtrate ceases to have a yellow colour, which the first washings possess, owing to the excess of bichloride of platinum. Should the filtrate not be coloured, it shows that enough of the precipitant has not been used, and in such a case the operation should be recommenced, taking care to have the platinic chloride in excess, which is known by observing if the supernatant liquid, after the greater part of the crystals has fallen to the bottom, is yellow; the salt is to be thrown upon a filter, and washed with alcohol as above directed. The filter should be carefully deprived of dust, dried at 212° Fahr. (100° C.), till the weight remains constant, before introducing the yellow crystalline compound; and after the substance has been thoroughly dried and weighed, the difference between the latter weighing of the paper and salt, and that of the paper alone, is the ammonium platino-chloride.

As a check upon the determination, the platinum compound may be introduced into a counterpoised porcelain crucible, and heated gently to redness, when all the constituents of the precipitate, except the platinum, are expelled. The metal remains in the form of a black spongy powder, which is weighed, and from its quantity the ammonia contained in the original precipitate ascertained by calculation. During the ignition of the ammonium platino-chloride, the heat must at first be applied very gently, and the crucible kept covered, lest the too rapid evolution of ammonium chloride should carry off some of the platinum mechanically, and give rise to an error. Towards the end of the operation the heat may be increased until no more vapours are observed; the crucible is then allowed to cool, and weighed.

When the ammoniacal compounds are insoluble in alcohol, they are analyzed by a more difficult way than either of the methods already described. The salt is ground with soda lime, and the mixture heated in a combustion tube, in the same way that an organic analysis is conducted. Soda lime is prepared by slaking pure caustic lime with a solution of sodium hydrate of such a strength that one part of the caustic alkali will be equal to two of the lime; it is then heated in a Hessian crucible to dull redness, and, after cooling, pulverized and retained for use in stoppered bottles.

Fig. 19.



Will and Warrentrap's nitrogen bulbs are connected to the end of the tube containing the mixed ammoniacal salts and soda lime by a perforated cork; the bulbs of the apparatus are filled with hydrochloric acid of 1·20 specific gravity, for the purpose of retaining the ammonia which is disengaged from the heated material in the tube. Fig. 19 shows the arrangement as here indicated.

a is the combustion furnace, made of sheet iron (Hofmann's gas combustion furnace is now generally used instead), and resting upon a tripod, or supported upon bricks on a table or cast-iron plate; b, the combustion tube, about 16 inches in length, and made of hard German glass, which bears the high temperature without fusing. The diameter of the tube should be about $\frac{5}{8}$ of an inch, and one end should be drawn out to a point, sealed at the extremity, as seen in the engraving. The mouth of the tube is closed by a perforated cork, into which a small tube is introduced, and which is connected to the nitrogen apparatus, C, by means of a caoutchouc connecter, *a*. The nitrogen apparatus has four bulbs, which are filled with hydrochloric acid to the level represented; the apparatus rests upon a convenient support, D. By placing the long limb of the bulbed tube in a small glass filled with the acid, and applying suction to the other end, it is readily filled to the proper height. Great care must be taken that too much acid is not admitted, as then there would be a risk of spoiling the analysis by the liquid flowing back into the combustion tube.

Before proceeding to the determination, the substance should be thoroughly dried, either in the water-bath or over sulphuric acid in the exhausted receiver of an air-pump; 10 to 20 grains are then taken and mixed intimately with the soda lime in an agate or glass mortar, which should be placed upon a large sheet of glazed paper, to prevent the loss of any particles that may be accidentally dropped during the grinding and filling of the tube. As much of the soda lime is put into the tube as is sufficient to fill about ¾ of an inch, and then the mixture of the substance under examination and the lime compound is introduced as speedily as possible. The mortar is rinsed with successive small quantities of the powdered soda lime, and these are added to fill up the empty part of the tube to within 2 inches of its mouth. A loose plug of asbestos is now inserted, and the cork with small tube tightly fitted to it; a space through which the products of the combustion may traverse the tube is made by holding the latter in the hand, and giving it a few gentle taps horizontally against the table; the contents aggregate more closely, and an empty space is formed in the upper part. The tube is now placed in the furnace with the pointed end upwards, as seen in the figure, and the nitrogen apparatus attached by means of the connecter. Care must be exercised that all the joinings are air-tight; this the operator may ascertain by holding a glowing piece of charcoal to the inner bulb, till a few bubbles of expanded air escape to the middle one; if, on removing the coal, the liquid assumes the original level the connections are air-tight. Red-hot pieces of charcoal are now applied to the posterior part of the tube for a short time, to expel the air contained in the apparatus; and after that the pieces are placed at the front end, and gradually added to as the contents become decomposed, till the whole of the tube is at a low red heat. Particular pains should be taken to eliminate the ammonia gradually and steadily, and, above all, not to allow the heat to fall at any part of the tube till all the ammonia contained in that part is expelled; for on removing the coals a vacuum is formed, which causes the reflux of the hydrochloric acid from the nitrogen apparatus into the tube. Hence the coals should be applied to a fresh part before the matter already decomposing is completely exhausted.

When no more ammonia is given off, the pointed end of the tube is broken by a forceps, and suction applied to the long arm of the nitrogen apparatus, in order to draw over the last traces of ammonia that might remain in the apparatus; after which it is detached, and the chloride of ammonium solution transferred to a beaker glass, or platinum dish, together with the water used to rinse the bulbs, and the whole evaporated to dryness.

The residue thus obtained is dissolved in as small a quantity as possible of distilled water, filtered, and the filtrate and washings precipitated by platinic chloride; the solution is then evaporated, and treated with alcohol. The remainder of the operation is conducted in the same way as already described. The results, when the operation is carefully performed, are very accurate.

The soda-lime process may be shortened by taking a known weight of pure hydrochloric acid, the quantity of real acid in which may be ascertained either by specific gravity or by an acidimetrical examination. In this case, after the ammonia from the mixture in the combustion tube has been absorbed, the contents of the nitrogen apparatus are transferred to a beaker glass together with the washings, and the excess of acid neutralized with a standard solution of ammonia.

Peligot determines this excess of acid by dissolving caustic lime in a solution of sugar, and neutralizing the acid with the solution thus obtained. The liquid is preserved from contact with carbonic acid in well-stoppered bottles.

The saccharate of lime thus formed has an alkaline reaction, and neutralizes acids like an alkaline carbonate. Its saturating power is tested with a dilute solution of pure concentrated sulphuric acid.

Estimation by Bromized Sodium Chloride.—A standard solution of strongly alkaline sodium chloride containing bromine sets free nitrogen when poured into a solution of ammonia. To prepare the solution:—Dissolve 1 part of sodium carbonate in 15 parts of water, cool the liquid with ice, and saturate it with chlorine whilst still cool, and add sufficient strong solution of sodium hydrate to render the whole caustic. Before using, add bromine in the proportion of 2 to 3 grains to the litre. (50 c.c. of this solution will decompose fully 2 grains of ammonium chloride). The solution is titrated with a solution of sodium arsenite containing 4·95 grm. As_2O_3 in 1 litre (1 c.c. = ·000566 grm. NH_3) (see Chlorine).

Estimation by Nessler's Solution (see Water).—When Nessler's solution (a solution of mercuric iodide in potassium iodide and potassium hydrate) is added to a certain volume of fluid containing a very minute unknown quantity of ammonia, a certain tint is produced. And the unknown quantity of ammonia may be determined by imitating this tint with a known quantity of ammonia.

The solutions used are:—1. A standard solution of ammonia (1 c.c. = 1 mgrm. NH_3). This is prepared by dissolving ·315 grm. of ammonium chloride in 1 litre of water. 2. Nessler's solution.

Potassium iodide, .	3·5 grm.
Mercuric chloride,	1 6 grm.
Water,	40 c.c.
Potassium hydrate solution,	*quant. suff.*

The potassium iodide is dissolved in 10 c.c. of water, the mercuric chloride in 30 c.c. of water. The latter solution is then gradually added to the former till a permanent precipitate is produced. Sufficient potash solution is then added to make the fluid measure 100 c.c.

The test glasses should be colourless and of equal size. They should be marked at 100 c.c., and the mark should be at the same height in each cylinder.

The process is carried out thus:—The solution to be tested is placed in one of the cylinders, made up to 100 c.c. with water, and 1·5 c.c. of NESSLER'S solution mixed with it by means of a pipette. The tint produced is carefully observed, and then imitated as nearly as possible by running into the other cylinder as many tenths of a c.c. of ammonia as it is imagined will produce the same effect. The second cylinder is then filled up to 100 c.c. with water, 1·5 c.c. of NESSLER'S solution added, and after allowing the whole to stand a few minutes, the tints of the contents of the two cylinders compared. If not alike, a fresh experiment is necessary. When the solution contains more than 1 mgrm. of ammonia in 100 c.c., the tint produced is far too dark for correct estimation.

ANÆSTHETICS (French, *anesthésiques;* from ἀ priv., and *αἰσθάνομαι*, to feel) is the name given to certain substances which, when introduced into the circulation, are capable of depriving the patient of the power of motion and of sensation. These agents are now largely used in therapeutics and in dentistry, for producing insensibility to the pain necessarily attendant upon surgical operations, and also as remedial agents in certain diseases characterized by great excitement of the sensorial functions.

Although it had long been known that narcotics, when administered in sufficiently large doses, produced coma and insensibility, the use of anæsthetics for the alleviation of pain is of comparatively recent date. An American, Dr. JACKSON, first suggested their use in 1846, and immediately afterwards they were successfully employed in dentistry by Dr. MORTON, and also by the American surgeons, WARREN, BIGLOW, and HAYWARD. On the 19th of December in the same year LISTON, the eminent surgeon, and Mr. ROBINSON, a dentist, operated on patients rendered insensible by the inhalation of ether vapour. In 1847 ether was employed in England and in France, and towards the end of that year FLOURENS pointed out the anæsthetic properties of chloroform; to Dr. SIMPSON of Edinburgh, however, we are indebted for the introduction of the use of chloroform in surgical and obstetrical practice. Dr. SNOW in 1849 published a work on the inhalation of ether, and also discovered that amylene was capable of producing effects similar to those of chloroform; the latter, however, is now almost invariably used in surgical operations, as its action is much more rapid than that of ether. Amylene is intermediate in rapidity of action between chloroform and ether; but as two out of the few cases in which it was tried proved fatal, its use was discontinued. Methylene dichloride, also, has recently been recommended by Dr. RICHARDSON as an anæsthetic, but it has the disadvantage of causing great depression.

These agents are administered through the respiratory organs by inhaling the vapour mixed with air. For this purpose some of the chloroform is poured on to a sponge or handkerchief, which is then applied to the mouth and nostrils of the patient in such a manner that the air which passes into his lungs is saturated with the vapour. Ether is administered in the same way. Dr. SNOW, who has paid much attention to this matter, invented a special form of apparatus for inhaling the vapour.

The first effect produced by the administration of the anæsthetic agent is a species of intoxication caused by its action on the cerebral lobes, and as this action extends to the cerebellum the patient becomes incapable of directing his movements—a result similar to that of alcoholic intoxication. In the next stage the spinal cord is attacked, unconsciousness supervenes, and all powers of motion and sensation are lost. The individual is now said to be in a state of *anæsthesia;* but the heart beats, breathing continues, and the other essential functions of the body are carried on. If, however, the exhibition of the anæsthetic agent is still continued, the temperature of the body becomes lowered, the movements of respiration and circulation become impaired, the heart ceases to beat, and death finally ensues.

The introduction of anæsthetics into surgical practice has greatly contributed to its progress: the patient being motionless and free from pain, the operator is enabled to perform with much greater delicacy and readiness; moreover, in the reduction of dislocations and of hernia, the muscles being flaccid, the obstacle produced by their contraction is removed.

M. VELPEAU endeavoured to produce *local anæsthesia*, or insensibility of that part of the body to be operated on, by means of a refrigerating mixture of ice and salt; it was, however, found to be very unmanageable. Since then local anæsthesia has been successfully obtained by means of a spray of ether directed upon the part; the intense cold produced by the rapid evaporation of the ether entirely depriving it of sensation.

See CHLOROFORM, ETHER, and NITROUS OXIDE or laughing gas, for methods of preparation and properties. Various other agents, such as amylene, ethyl chloride, ethyl nitrate, benzene, and carbon bisulphide, have been proposed as anæsthetics; but from their injurious effects they have never been brought into use.

ANILINE AND ANILINE DYES—ANILINE. The term Aniline, or Aniline oil, is used commercially to indicate a variable mixture of bodies, amongst which certain members of the series of organic bases known as the *Aniline homologues* greatly preponderate. Aniline itself, the parent member of this series, is indicated by the formula C_6H_5,NH_2; the formulæ of all the true homologues of aniline are deducible from this parent symbol by substituting for one or more of the five H symbols in the radical C_6H_5 a corresponding number of univalent hydrocarbon radicals of the methyl series, just as the formulæ of benzene homologues are deducible from the symbol of benzene by a similar process. (*Vide* article, BENZOL.) The main constituents of commercial aniline oils consist of the lower members of this series, viz. :—

Name of Base.	Rational Formula.	Dissected Formula.	Boiling Point. Degs. C.	Melting Point.
Aniline, ...	C_6H_7N	$C_6H,\ NH_2$	182°	—8°
Para-toluidine, ..	C_7H_9N	$C_6H^4\left\{\begin{matrix}NH_2\\(CH_3)_p\end{matrix}\right.$	200°	+ 45°
Meta-toluidine, ..	C_7H_9N	$C_6H_4\left\{\begin{matrix}NH_2\\(CH_3)_m\end{matrix}\right.$	199°	liquid at —20°
Various Xylidines, ...	$C_8H_{11}N$	$C_6H_3\left\{\begin{matrix}NH_2\\CH_3\\CH_3\end{matrix}\right.$	212° to 216°	—
Various Cumidines, ..., &c., &c.	$C_9H_{13}N$	$C_6H_2\left\{\begin{matrix}NH_2\\CH_3\\CH_3\\CH_3\end{matrix}\right.$	About 225°	Some liquid some solid, one melts at 60°.

Just as various isomeric modifications of certain homologues of benzene are known, the formulæ of which are distinguished one from the other by special devices in their "dissection:" so various isomeric modifications of the higher aniline homologues are known, denoted by analogous methods. Comparatively few of these have as yet been submitted to special study; but in the toluidine series all three of the isomerides predictable in accordance with the symbolic system of KEKULÉ for the notation of benzene derivatives are actually known (*vide* article BENZOL), although only two (para- and meta- toluidine), have as yet been shown to exist in commercial aniline oils.

In addition to these bodies, the aniline oils of commerce usually contain small quantities of other substances, for the most part formed as bye-products during the manufacture of the oils; the chief of these constituents are :—Diamidobenzene, $C_6H_4(NH_2)_2$, Diamidotoluene, $C_6H_3\left\{\begin{matrix}CH_3\\(NH_2)_2\end{matrix}\right.$; higher homologues thereof :—Paraniline, $C_{12}H_{14}N_2$; Azobenzene, $C_{12}H_{10}N_2$; higher homologues thereof :—Xenylamine, $C_6H_4\left\{\begin{matrix}C_6H_5\\NH_2\end{matrix}\right.$; Acetanilide, $\left.\begin{matrix}C_6H_5\\C_2H_3O\\H\end{matrix}\right\}N$; Para acet-toluide, $\left.\begin{matrix}C_6H_4(CH_3)_p\\C_2H_{30}\\H\end{matrix}\right\}N$; Meta acet-toluide, $\left.\begin{matrix}C_6H_4(CH_3)_m\\C_2H_3O\\H\end{matrix}\right\}N$, &c.

ANILINE (*par excellence*), AMIDOBENZENE, or PHENYLAMINE.—This base was first discovered by UNVERDORBEN in 1826, as a product of the dry distillation of indigo; on account of the facility with which its salts crystallize, he applied the term *Crystalline* to it. In 1834, RUNGE obtained from coal tar a substance to which he gave the name *Kyanol*, on account of its power of producing purple or violet-blue tints with bleaching powder. In 1840, FRITZSCHE found that a volatile liquid base is produced, by acting on indigo and certain of its derivatives, with caustic potash; to this he gave the name ANILINE, from *anil*, the Portuguese for indigo. Soon after ZININ obtained a substance, which he termed *Benzidam*, by reducing nitrobenzene by alcoholic ammonium sulphide, and FRITZSCHE showed that this substance was identical with his aniline. In 1843, HOFMANN showed that crystalline, kyanol, aniline, and benzidam are one and the same substance. In 1856, PERKIN discovered the production of mauve by the oxidation of aniline sulphate by potassium dichromate; this process he subsequently patented. The manufacture of aniline speedily became a recognized industrial operation, the cheapest source being nitrobenzene, which was derived from the benzene occurring in coal tar. The distillation of the latter hydrocarbon from the waste products of gas works is now a distinct trade (*vide* article COAL TAR DISTILLATION). The discovery of fuchsine by VERGUIN, in 1858, as a product of the action of certain dehydrogenizing agents on commercial aniline oils, greatly stimulated the growth of this industry; and the subsequent discoveries of triphenyl rosaniline (Bleu de Lyons), ethylated and methylated rosanilines (HOFMANN's blues and violets), aldehyde green, iodine green, violets de Paris, diphenylamine blue, &c., &c., added rapidly in succession to the magnitude and importance of the trade in colours derived from aniline oils as starting point. The value of the aniline dyes now yearly manufactured, is estimated by VERSMANN to exceed £2,000,000 sterling.

The chief processes by which aniline can be formed are these :—

A. From BENZENE.

1. By the passage of a mixture of benzene and ammonia through red hot tubes—(Berthelot).

$$\underset{\text{Benzene.}}{C_6H_6} + \underset{\text{Ammonia.}}{NH_3} = H_2 + \underset{\text{Aniline.}}{C_6H_5,NH_2}.$$

2. By the conversion of benzene into nitrobenzene and subsequent reduction by nascent hydrogen, or by other reducing agents equivalent thereto.

$$C_6H_6 + NO_2,OH = H,OH + C_6H_5,NO_2$$
$$C_6H_5.NO_2 + 3H_2 = 2H_2O + C_6H_5,NH_2.$$

The following are the principal methods by which the reduction may be effected :—

a Action of alcoholic sulphuretted hydrogen or sulphides—(*Zinin*).
b " acetic acid and metallic iron—(*Béchamp*).
c " zinc and alcoholic hydrochloric acid—(*Hofmann*).
d " zinc dust and hot water—(*Kremer*).
e " tin and hydrochloric acid—(*Scheurer Kestner*).
f " hydriodic acid. at 104° C.—(*Mills*).
g " caustic soda and grape sugar—(*Vohl*).
h " alkaline arsenites—(*Wöhler*.
i " stannous chloride—(*Kekulé*).
k Distillation with alcoholic potash, *inter alia*—(*Mitscherlich*).
l Passage through the animal organism—(*Letheby*).
m Action of iron filings and very dilute hydrochloric acid—(*Brimmeyr*).
n Water and particles of iron covered superficially with copper, by means of a short immersion in copper sulphate solution—(*Coblentz*).
o Water and solution of cuprous oxide in ammonia—(*Wagner*).
p Water and carbon disulphide at 160° C.—(*Schlaydenhauffen*).

B. From PHENOL.

1. By heating with ammonia at 300° C., for two or three weeks—(LAURENT, HOFMANN).

$$C_6H_5{,}OH + NH_3 = H_2O + C_6H_5{,}NH_2.$$

(Berthelot finds that only traces of aniline are thus formed after heating to 280°C. for twenty-four hours, a little more being produced at 360° C.)

2. By transformation into phenyl chloride and heating with ammonium hydrochloride—(DUSART and BARDY). GIRARD and DE LAIRE have been unable to verify this reaction.

C. From AMIDOBENZOIC ACIDS AND CERTAIN OF THEIR ISOMERIDES BY HEATING, EITHER ALONE OR TOGETHER WITH AN ALKALI.

1. Amidobenzoic acid (Anthranilic acid)—

$$C_6H_4\left\{\begin{matrix}CO{,}OH\\ NH_2\end{matrix}\right. = CO_2 + C_6H_5{,}NH_2$$

2. Salicylamide—

$$C_6H_4\left\{\begin{matrix}OH\\ CO{,}NH_2\end{matrix}\right. = CO_2 + C_6H_5{,}NH_2$$

—(*Hofmann and Muspratt*).

3. Nitrotoluene—

$$C_6H_4\left\{\begin{matrix}NO_2\\ CH_3\end{matrix}\right. = CO_2 + C_6H_5NH_2$$

—(*Hofmann and Muspratt*).

D. From OTHER SOURCES.

Destructive distillation of indigo—(*Unverdorben*).
" " coal—(*Runge*).
" " turf—(*Vohl*).
Action of caustic potash on indigo, isatin, &c.—(*Fritzsche*).

Of these reactions only those falling under class A can be made commercially available, the extraction of the aniline ready formed in coal and other tars being too costly. Out of these processes only 2. *a*, *b*, *c*, *d*, *g*, and *h*, appear to have been used on anything like a manufacturing scale; process 2. *b* (BÉCHAMP'S) being the one now almost universally employed, not only for the preparation on the large scale of aniline itself, but also of the mixtures known as aniline oils.

Pure aniline is a perfectly colourless oily fluid, which refracts light strongly, and has a weak aromatic odour; it is but sparingly soluble in water, but is dissolved with ease by ether, alcohol, carbon disulphide, and hydrocarbons. It boils at 182° C., and solidifies in a freezing mixture to a crystalline mass melting at —8° (LUCIUS: this only takes place when the substance is exceedingly pure, ordinarily pure aniline not solidifying at —20° C.): its specific gravity at 16°C. is 1·02. By exposure to air and light it becomes brown, probably by oxidation. Its basic properties are well-marked, a lengthy series of well-defined salts being obtainable from it; it has scarcely any action on vegetable colours, not affecting either turmeric or litmus, although it turns violet dahlia tincture green: when boiled with solution of ammoniacal salts it expels ammonia, forming aniline salts; cold solution of ammonia, however, precipitates aniline from its salts. Aniline throws down the hydrates from solutions of many metallic salts, *e.g.*, iron, zinc, alumina, &c., but not of others, *e.g.*, manganese, cobalt, nickel, lead, and chromium. It is a powerful narcotic poison.

Commercially pure aniline is prepared as in the manufacture of aniline oils generally; it may also be obtained from the lighter kinds of commercial oils by successive distillations, the first runnings being in each case collected apart and redistilled. For the preparation of certain dyes an oil containing ninety-five per cent. at least of pure aniline, and not more than five per cent. of the higher homologues, is required. The separation of the higher homologues is considerably facilitated by the addition of from ten to twenty per cent. of sulphuric acid to the mixture of bases before distilling, collecting apart the distillate at 182° to 185° C., and treating this repeatedly in the same way.

TOLUIDINE.—Three isomeric modifications of this base are known, distinguished as para-, meta-, and ortho-toluidine respectively.

Paratoluidine.—$C_7H_9N = C_6H_4\left\{\begin{matrix}NH_2\\ CH_3.\end{matrix}\right.$ This was discovered by HOFMANN and MUSPRATT in 1845, being derived from the action of reducing agents on nitrotoluene, obtained by nitrating toluene obtained from balsam of tolu. CHAUTARD also obtained it in small quantity by acting with caustic potash on the yellow resin formed when turpentine is oxidized by nitric acid. It is also formed by the reducing action of hydriodic acid at 180°-200° C. on pure nitrobenzoic acid, or on the amidobenzoic acid, derived thence by reduction (ROSENSTIEHL)—

$$C_6H_4\left\{\begin{matrix}NH_2\\ CO{,}OH\end{matrix}\right. + 6HI = 3I_2 + 2H_2O + C_6H_4\left\{\begin{matrix}NH_2\\ CH_3\end{matrix}\right.$$

and by heating methylaniline hydrochloride in sealed tubes to 350° for a day (HOFMANN)—

$$C_6H_5{,}NH{,}CH_3 = C_6H_4\left\{\begin{matrix}NH_2\\ CH_3.\end{matrix}\right.$$

This reaction is one of the class where "change of position," in the various groups of symbols that make up the dissected formulæ of the materials and products is said to occur.

When perfectly pure, paratoluidine melts at 45° C., and boils at a temperature variously stated at from 198° to 200° C., by different observers. Minute quantities of foreign substances greatly lower its melting point; hence 40° C. was a long time considered as the true melting point. In chemical character it closely resembles aniline.

Pure paratoluidine is not commercially manufactured; it may be obtained by reducing paranitrotoluene (*vide* article BENZOL) by nascent hydrogen, and crystallizing the resulting product from alcohol; or if larger quantities are required, it may be extracted from those aniline oils that boil near 200° C. by the following process, described by BRIMMEYR, viz.: fractional distillation, the portions boiling between 195° and 205° C. being collected apart; this fraction is then heated with half its weight of oxalic acid and four times its weight of water, until solution is effected; the hot liquor is then cooled to 80° C. and rapidly filtered: crystals of paratoluidine oxalate separate, from which the base is obtained by pressing, and then boiling with ammonia solution to which enough alcohol has been added to yield a clear solution of paratoluidine. On cooling crystals of the base form, which may be recrystallized from alcohol (or better, petroleum distillates boiling at 80°–100° C. —H. MÜLLER); the oxalate may be recrystallized with advantage before the separation of the free base (NOAD).

Metatoluidine.—ROSENSTIEHL discovered in 1868 that the substance boiling at 198° C., and possessing the composition C_7H_9N, occurring in ordinary aniline oils, consisted mainly of a mixture of paratoluidine and an isomeride, since recognized as metatoluidine, but termed *pseudotoluidine* by its discoverer. This mixture exhibits the composition and boiling point of paratoluidine, but refuses to crystallize at ordinary temperatures; at 0° C., however, and in presence of a few drops of water, or a crystal of paratoluidine, much solid paratoluidine separates; by filtration and pressure this is separated, and the yet liquid mixture of bases is again treated in the same way. The portion finally remaining liquid is converted into neutral oxalate and then digested with anhydrous ether, in which menstruum paratoluidine oxalate is almost insoluble, whilst metatoluidine oxalate dissolves readily therein (aniline oxalate is but slightly soluble in anhydrous ether). The ethereal solution is evaporated, and the residue again treated with ether; finally, the metatoluidine oxalate thus separated is crystallized from water or alcohol, and decomposed by caustic soda.

The relations between metatoluidine and other benzene derivatives have been studied by ROSENSTIEHL, BEILSTEIN and KUHLBERG, HUEBNER and WALLACH, KÖRNER, WROBLEWSKY, and others, from whose researches it results that when toluene is nitrated two isomeric nitrotoluenes are formed by the reaction. One of these is solid, and forms paratoluidine only on reduction; the other is liquid, and produces metatoluidine. On the other hand, either para- or meta- toluidine, when treated with nascent hydrogen evolved by heating with strong hydriodic acid, gives rise to *absolutely the same toluene* in each case, this toluene being in either instance capable of producing both solid and liquid nitrotoluene on nitration. Hence it results that commercial aniline oil necessarily contains both para- and meta- toluidine, produced by the reduction of the para- and meta-nitrotoluenes simultaneously formed by the nitration of the toluene contained in commercial benzol: only one toluene, however, exists in this substance (*vide*, article BENZOL).

Metatoluidine is also obtained by the following processes:—Reduction of meta-nitrotoluene resulting from the decomposition of the diazo-derivative of the nitrotoluidine formed by the reduction of dinitrotoluene melting at 70·5, produced by the continued action of nitric acid on toluene (BEILSTEIN and KUHLBERG). Passage of the vapour of the amidotoluic acid, resulting from the action of nitric acid on xylene, over soda lime (BEILSTEIN and KUHLBERG):—

$$C_6H_3\left\{\begin{matrix}NH_2\\ CO,OH\\ CH_3\end{matrix}\right. = CO_2 + C_6H_4\left\{\begin{matrix}NH_2\\ CH_3\end{matrix}\right.$$

Action of nascent hydrogen (zinc and hydrochloric acid, sodium amalgam, &c.) on the nitrobromotoluene resulting from the action of strong well-cooled nitric acid on solid bromotoluene melting at 25°·4 C. (KÖRNER, ROSENSTIEHL and NIKIFOROFF.)

$$C_6H_3\left\{\begin{matrix}NO_2\\ Br\\ CH_3\end{matrix}\right. + 4H_2 = HBr + 2H_2O + C_6H_4\left\{\begin{matrix}NH_2\\ CH_3\end{matrix}\right.$$

Metatoluidine also occurs in the aniline obtained from indigo (ROSENSTIEHL).

Pure metatoluidine, when perfectly anhydrous, boils at 199° C.; but the presence of traces of moisture lowers its boiling point to 196° C.: it does not solidify at —20° C. In general properties it much resembles paratoluidine, but differs in its crystalline form and in the solubility of its salts; it also gives rise to derivatives which exhibit considerable difference in boiling and melting points, &c., from the corresponding derivatives of paratoluidine. A marked difference in the action of bleaching powder on the two serves as a useful qualitative test; if the solution oxidized by bleaching powder be shaken up with ether, and the ethereal extract agitated with acidulated water, no result ensues in the case of paratoluidine (nor of aniline), but a magnificent tint resembling that of permanganate solution is developed with metatoluidine.

ROSENSTIEHL employs three methods for the separation of metatoluidine from commercial toluidine, viz.:—A process depending on the different solubility of the acid oxalate, the paratoluidine salt requiring 125 parts of water for solution, whilst the metatoluidine salt is much more soluble; one taking advantage of the tendency possessed by the hydrochloride of each base to yield supersaturated solutions, from a mixture of which the one salt or the other can be made to crystallize by dropping in a crystal of the required kind; and a method consisting in fractional saturation with an acid, preferably sulphuric acid—paratoluidine is first taken up, and metatoluidine can then be distilled off by means of steam.

BINDSCHLEDER gives the following commercial process founded on ROSENSTIEHL'S observations:—Commercial "toluidine" (a mixture of para- and meta- toluidine with a small percentage of aniline) is distilled, the portion passing at 198° C. being collected apart; to 200 kilos. of this, 25 litres of water are added, in which 2½ kilos. of oxalic acid have been previously dissolved; 6 litres of hydrochloric acid at 20° Beaumé are then added, and the whole boiled and cooled to 60° C. and rapidly filtered; paratoluidine oxalate is thus thrown down. To the filtrate 2 kilos. of oxalic acid are then added, whereby a mixture of oxalates of para- and meta-toluidine is precipitated, from which the bases are regained by means of soda, and the mixture is then used over again in the first part of the process. The filtrate is distilled with soda, when metatoluidine is obtained sufficiently pure for manufacturing purposes. (Berichte der Deut. Chem. Ges., vol. vi. p. 448.)

SCHAD separates metatoluidine from aniline oils boiling near 200° C., by adding to every 10 lbs. of oil, nitric acid of specific gravity 1·2, in sufficient quantity to convert it into nitrate (quantity not stated). The hot liquid is cooled and well stirred, and the crystalline mass thoroughly expressed; the solid residue is dissolved in as much boiling water as will give a solution of sp. gr. 1·1 (while hot?), the solution cooled and stirred. The crystals formed are again pressed out and dissolved in boiling water to sp. gr. 1·075, allowed to crystallize, and again expressed, and finally again dissolved to sp. gr. 1·05, crystallized and expressed. These last crystals are nearly pure metatoluidine nitrate, from which the free base is readily obtained by distillation with soda. Higher homologues are still present to some extent, but these are separated by converting the mixture into hydrochlorides, heating with water as before. Finally, a metatoluidine boiling constantly at 197° C., is obtained, the yield being about 1 lb. or 10 per cent. of the aniline oil used.

Commercial toluidine prepared by COUPIER, and boiling constantly at 198° C., was found by ROSENSTIEHL to contain:—Paratoluidine, 62 p.c.; metatoluidine, 36 p.c.; aniline, 2 p.c. On the other hand, commercially pure aniline contained:—Aniline, 95 p.c.; mixture of para- and meta- toluidine, 5 p.c. It does not appear that the ratio between the para- and meta- toluidine present in commercial aniline oils is at all constant; slight differences in the circumstances attending the nitration of the hydrocarbons employed naturally produce differences in the relative quantities of para- and meta- nitrotoluene formed *inter alia*.

Orthotoluidine.—The existence of this third isomeride in commercial aniline oil has not yet been definitely proved, although it is not improbable. It was obtained by BEILSTEIN and KUHLBERG by the reduction of the orthonitrotoluene formed by decomposing with alcoholic potash the nitro-acet-toluide produced by nitrating para-acet-toluide, and converting the resulting nitrotoluidine into nitrotoluene by GRIESS' process (*vide* article BENZOL).

The following table illustrates the differences between these three isomeric toluidines:—

	Paratoluidine.	Metatoluidine.	Orthotoluidine.
At ordinary temperature, ...	Solid.	Liquid.	Liquid.
Melting point,...	+45	Does not solidify at—20°	Does not solidify at—13°
Boiling point,....	198°, various observers. 200°, Beilstein and Kuhlberg.	198° Rosenstiehl, 199° Beilstein and Kuhlberg.	197° Beilstein and Kuhlberg.
Specific gravity,	Nearly identical with water. 0·9965 Girard and De Laire. 1·0017, other observers.	1·0002 at 16·3, Rosenstiehl.	0·998 at 25°. Beilstein and Kuhlberg.
Colour reaction with bleaching powder & ether, &c.,................	Nil.	Permanganate tint.	Permanganate tint.
Melting point of acet-toluide......	147°	102°	65° to 65·5°
Boiling point of acet-toluide,.....	300° to 307°	295°	302° to 304°
Solubility of acet-toluide,.....	1000 water dissolve 0·886 at 22°	1000 water dissolve 8·5 at 19°	1000 water dissolve 4·3 at 13°

Xylidine.—The aniline homologues from the reduction of the nitroxylenes in commercial nitrobenzol have not been minutely studied. HOFMANN and MARTIUS extracted from aniline tailings, *queues d'aniline*, a xylidine boiling at 212° C.; and TAWILDAROW prepared from nitro-isoxylene, a xylidene boiling at 216° C., sp. gr. 0·935 at 18°·5 C. The xylidine present in aniline oils is probably a mixture of the product of TAWILDAROW and the corresponding body derived from nitro-paraxylene. CAHOURS gives 214° C. as the boiling point of coal tar xylidine, and BEILSTEIN 215° C.

Besides these several other isomerides are known, but are probably not contained in aniline oils.

Cumidine.—SCHAFER has obtained from the nitrocumene derived from pseudo-cumene (trimethyl benzene) which melts at 71° C., a cumidine which crystallizes in needles melting at 60° C., whilst FITTIG and STORER have obtained from the nitrocumene derived from mesitylene, a cumidine which does not solidify at 0° C.; to this base the term *mesidine* is applied. Probably the cumidine occurring in aniline consists of a mixture of both of those isomerides and possibly others; the cumidine obtained from coal tar cumene (mixture of isomerides) is liquid at ordinary temperatures, and boils at 225° C.

Besides the aniline series of bases, commercial aniline oils also contain smaller or larger quantities of the following and other substances:—

Diamidobenzene (*phenylene-diamine*).—By the reduction of dinitrobenzene occurring in the nitrobenzol used, there is produced, firstly, a nitraniline, and secondly, a diamidobenzene.

$$C_6H_4\left\{\begin{matrix}NO_2\\NO_2\end{matrix}\right. + 3H_2 = 2H_2O + C_6H_4\left\{\begin{matrix}NH_2\\NO_2\end{matrix}\right.$$

$$C_6H_4\left\{\begin{matrix}NH_2\\NO_2\end{matrix}\right. + 3H_2 = 2H_2O + C_6H_4\left\{\begin{matrix}NH_2\\NH_2\end{matrix}\right..$$

Three diamidobenzenes are actually known, only one of which occurs in aniline oils, viz., that derived from the reduction of the dinitrobenzene formed by the continued action of nitric acid on benzene. It is a solid crystalline body melting at 63° C. and boiling at 287°C.; by the action on this of nitrous acid, phenylene brown, $C_{12}H_7N_2(NH_2)_3$, is formed. (*vide* Aniline brown).

Diamido-toluene.—By the further nitration of paranitro-toluene there is formed a dinitrotoluene melting at 71° C. (*vide* BENZOL). By the action of reducing agents a nitrotoluidine and a diamidotoluene are formed:—

$$C_6H_3\left\{\begin{matrix}CH_3\\NO_2\\NO_2\end{matrix}\right. + 3H_2 = 2H_2O + C_6H_3\left\{\begin{matrix}CH_3\\NH_2\\NO_2\end{matrix}\right.$$

$$C_6H_3\left\{\begin{matrix}CH_3\\NH_2\\NO_2\end{matrix}\right. + 3H_2 = 2H_2O + C_6H_3\left\{\begin{matrix}CH_3\\NH_2\\NH_2\end{matrix}\right..$$

This diamido-toluene melts at 99° C. and boils at 300° C. Diamido-xylenes and diamidocumenes are also probably present in high boiling aniline oils.

Paraniline.—HOFMANN has shown that aniline tailings (*queues d'aniline*) contain a solid body melting at 192° C. and boiling above 330° C. Beyond the fact that this substance is indicated by a formula double of that applied to aniline, little is known of its relation to that body or of its mode of formation.

Xenylamine.—$C_{12}H_9,NH_2$. HOFMANN has also found in aniline tailings a base which has the composition and properties of amidodiphenyl, *i.e.*, is related to diphenyl, C_6H_5,C_6H_5, as aniline is to benzene; it is a crystalline body melting at 45° and boiling at 322° C.

Azobenzene or *Azobenzide.*—This body, $C_{12}H_{10}O_2$, is formed from nitrobenzene by the action of a quantity of hydrogen insufficient to transform it into aniline:—

$$2C_6H_5,NO_2 + 4H_2 = 4H_2O + C_{12}H_{10}N_2.$$

By the action of nascent hydrogen it yields aniline, *inter alia;* conversely, certain oxidizing agents transform aniline into azobenzene. Nascent hydrogen also forms a body related to xenylamine just as diamidobenzene is to aniline, viz., *Benzidine* or *xenylene diamene* (diamidodiphenyl)—

$$C_{12}H_{10}N_2 + H_2 = C_{12}H_8\left\{\begin{matrix}NH_2\\NH_2\end{matrix}\right.$$

This latter substance is probably therefore a constituent of aniline oils. Azobenzene melts at 65°, and distils unchanged at 293° C., whilst benzidene melts at 118° C., and is partially decomposed by distillation.

Azotoluene.—This body is related to toluene, just as azobenzene to toluene; probably more than one modification exists in aniline oils. Bodies similarly related to the nitroxylenes and nitrocumenes are also likely to be present in the higher boiling aniline oils.

Acetanilide.—This body is formed by the action of heat on aniline acetate and in several other ways—

$$C_6H_5,NH_2,C_2H_3O,OH = H_2O + C_6H_5,NH,C_2H_3O$$

It forms a crystalline mass melting at 101° C. (GREVILLE WILLIAMS); 106°·5 C. (STAEDELER); 111° C. (GERHARDT); 112°–113° C. (MERZ and WEITH); and boiling at 295° C. Dilute alkaline solutions have little action on it, for which reason, if once formed in BÉCHAMP's process, it is apt to remain unaltered, and to lead to a considerable loss of aniline; fusion with caustic potash, however, readily transforms it into aniline and potassium acetate:—

$$C_6H_5,NH,C_2H_3O + KOH = C_6H_5,NH_2 + C_2H_3O,OK$$

Acet-toluide.—Two isomerides of this character occur in aniline oils, viz., the para- and meta-toluidine derivatives; these melt at 147° and 102° C., and boil at 306° and 295° C. respectively. Higher homologues, *e.g.*, acetoxylides, acetocumides, &c., are known, and without doubt are present in the higher boiling aniline oils.

It is wholly unknown whether any of the foregoing constituents of aniline oils, other than aniline and its homologues, have any influence on the tinctorial properties of the aniline colours made from oils containing them; for the most part these bodies are removed by fractional distillation of the aniline oil before it is used for fuchsine, and especially for methyl violet; still the presence of even traces may not improbably somewhat modify the nature of the reactions taking place, and may consequently have some influence on the character of the dye-stuff produced, and on its yield. It happens in several instances that whilst the action of certain reagents on a single homogeneous aniline base gives rise to no product possessed of tinctorial properties, the same substance produces valuable dyes when made to act on a mixture of bases nonproductive when separately treated. Thus the oxidizing materials which produce rosaniline when a mixture of aniline and paratoluidine is acted on, give rise to no red colour with pure aniline (HOFMANN), to a violet colouring matter, *violaniline* (GIRARD, DE LAIRE, and CHAPOTEAU). A red very similar to rosaniline, but differing from it in certain respects, is produced when aniline and metatoluidine are similarly treated; whilst a mixture of para- and meta-toluidine gives a third red under the same circumstances. On the other hand, neither para- nor meta-toluidine gives any red colour when subjected alone to this treatment (ROSENSTIEHL, HOFMANN). Similarly, pure xylidine gives no red, whilst a mixture of xylidine and aniline gives a fine crimson red dye (HOFMANN). Again, azobenzene has been shown by STAEDELER to form blue and violet colouring matters when heated with aniline or toluidine hydrochloride, the latter also yielding a ruby red compound. It may therefore readily happen, that the presence of a minute quantity of a body, inert as a dye-producer itself, may greatly affect the quality of the dye formed from the other substances simultaneously present; and it is by no means improbable that the success of various devices and "secret processes" practised by colour makers depends on such circumstances, the exact nature of the influence being unknown, and the process being arrived at in an empirical way.

Substituted Anilines.—Of the numerous bodies known from the researches of HOFMANN to be obtainable from aniline and its homologues by substitutive reactions, only that class is of commercial interest where the substitution is of a kind that gives rise to a secondary or a tertiary monamine, *i.e.*, which is symbolically indicated by the replacement of one or both of the H symbols in the NH_2, radical by the symbols of some hydrocarbonous radical: thus,

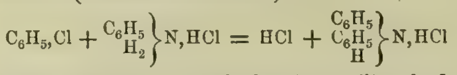
$$C_6H_5,NH_2 + CH_3I = HI,C_6H_5,NH,CH_3$$
$$C_6H_5,NH,CH_3 + C_2H_5Br = HBr,C_6H_5,N\left\{\begin{matrix}CH_3\\C_2H_5\end{matrix}\right.$$

Of the bodies thus producible, the following are the most important:—

Diphenylamine, $\left.\begin{matrix}C_6H_5\\C_6H_5\\H\end{matrix}\right\}N.$ This base is obtainable by the dry distillation of certain aniline dyes, *e.g.*, rosaniline, leucaniline, &c. (HOFMANN), and by the action of aniline on aniline salts (*e.g.*, the hydrochloride), or on a mixture of materials which give rise to the formation of an aniline salt, *e.g.*, aniline and a phenyl sulphonate (GIRARD, DE LAIRE, and CHAPOTEAU), the corresponding ammonium salt being formed

$$\left.\begin{matrix}C_6H_5\\H\\H\end{matrix}\right\}N + \left.\begin{matrix}C_6H_5\\H\\H\end{matrix}\right\}N,HCl = \left.\begin{matrix}C_6H_5\\C_6H_5\\H\end{matrix}\right\}N + \left.\begin{matrix}H\\H\\H\end{matrix}\right\}N,HCl$$

Also by that of nascent phenyl chloride on aniline hydrochloride (prepared by heating together phenol, sal-ammoniac, and hydrochloric acid), or by passing phenyl chloride or iodide and aniline vapour through a hot tube (DUSART and BARDY).

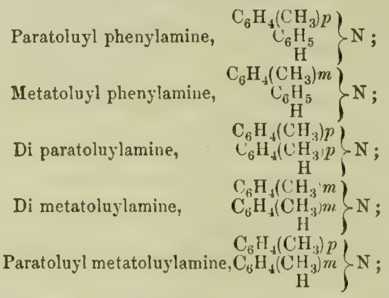


$$C_6H_5,Cl + \left.\begin{matrix}C_6H_5\\H_2\end{matrix}\right\}N,HCl = HCl + \left.\begin{matrix}C_6H_5\\C_6H_5\\H\end{matrix}\right\}N,HCl$$

It is also formed by simply heating aniline hydrochloride to 300° C., (GIRARD and DE LAIRE), or by treating aniline with potassium (not sodium), and acting on the product with phenyl bromide (MERZ and WEITH).

Diphenylamine is, when pure, a solid crystalline body, melting at 45°, and distilling without change at 310° C. It is chiefly characterized by its power of yielding deep blue products of great tinctorial power on treatment with certain oxidizing agents (*Vide* BLUE DYES *infra*).

A great number of higher homologues of diphenylamine are known. Commercial diphenylamine is made from a mixture of aniline and toluidine (para- and meta-), not unfrequently containing higher homologues: hence it may be expected to contain, in addition to diphenylamine, the following bases:—



Paratoluyl phenylamine, $\left.\begin{matrix}C_6H_4(CH_3)p\\C_6H_5\\H\end{matrix}\right\}N$;

Metatoluyl phenylamine, $\left.\begin{matrix}C_6H_4(CH_3)m\\C_6H_5\\H\end{matrix}\right\}N$;

Di paratoluylamine, $\left.\begin{matrix}C_6H_4(CH_3)p\\C_6H_4(CH_3)p\\H\end{matrix}\right\}N$;

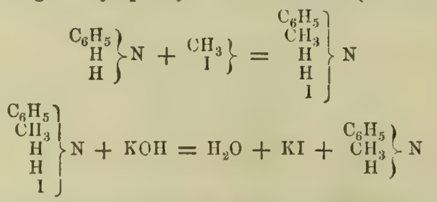
Di metatoluylamine, $\left.\begin{matrix}C_6H_4(CH_3)m\\C_6H_4(CH_3)m\\H\end{matrix}\right\}N$;

Paratoluyl metatoluylamine, $\left.\begin{matrix}C_6H_4(CH_3)p\\C_6H_4(CH_3)m\\H\end{matrix}\right\}N$;

Besides higher homologues. The existence of all these bodies, however, has not yet been absolutely proved; some of them have been described, but it is not yet proved that the bodies examined were not mixtures of isomerides.

Methyl diphenylamine, $\left.\begin{matrix}C_6H_5\\C_6H_5\\CH_3\end{matrix}\right\}N$, has been obtained by BARDY by the action of methylic alcohol on diphenylamine under pressure; by the action of oxidizing agents it forms blue and violet colouring matters.

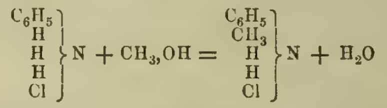
Methyl aniline, $\left.\begin{matrix}C_6H_5\\CH_3\\H\end{matrix}\right\}N$.—This base is obtainable by the action of methyl chloride, bromide, or iodide on aniline, and the action of caustic alkalies on the resulting methyl phenylium salt formed (HOFMANN).



$$\left.\begin{matrix}C_6H_5\\H\\H\end{matrix}\right\}N + \left.\begin{matrix}CH_3\\I\end{matrix}\right\} = \left.\begin{matrix}C_6H_5\\CH_3\\H\\H\\I\end{matrix}\right\}N$$

$$\left.\begin{matrix}C_6H_5\\CH_3\\H\\H\\I\end{matrix}\right\}N + KOH = H_2O + KI + \left.\begin{matrix}C_6H_5\\CH_3\\H\end{matrix}\right\}N$$

Methyl nitrate, also, forms much methyl aniline on heating to 100° C. with aniline; its use, however, requires caution, as dangerous accidents and explosions have occurred through the volalility of the nitrate and its detonating power, under conditions not thoroughly understood. It is producible much more cheaply by the reaction of methylic alcohol on aniline hydrochloride under pressure (BARDY, POIRRIER, and CHAPPAT), the reaction being

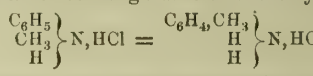


$$\left.\begin{matrix}C_6H_5\\H\\H\\H\\Cl\end{matrix}\right\}N + CH_3,OH = \left.\begin{matrix}C_6H_5\\CH_3\\H\\H\\Cl\end{matrix}\right\}N + H_2O$$

Methyl aniline hydrochloride is thus formed, from which the free base is obtainable by treatment with alkalies. Simultaneously with methyl aniline, dimethyl aniline hydrochloride is usually produced in variable quantities. It seems not improbable that this reaction is really due to the formation of a small quantity of methyl chloride which then attacks the aniline present, in accordance with HOFMANN'S reaction; instead of aniline hydrochloride a mixture of aniline and sal ammoniac may be used, or a mixture of aniline and methylamine hydrochloride. When pure, methyl aniline is an oily liquid, boiling at 192° C., yielding colouring matters in small quantities only by the action of oxidizing agents; when mixed with dimethyl aniline, or with higher homologues, *e.g.*, methyl toluidine, the yield is much greater.

Dimethyl aniline, $\left.\begin{matrix}C_6H_5\\CH_3\\CH_3\end{matrix}\right\}N$, is obtainable from methyl aniline by the same processes as those by which the latter is producible from aniline: it is a liquid, boiling at 202° C. (LAUTH), at 192° C. when perfectly pure (HOFMANN).

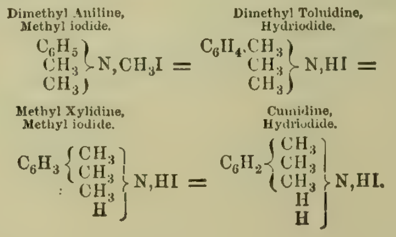
When the salts of methyl aniline are heated in a sealed tube to 350° C. for a day, they undergo a change of the kind referred to as "change of position," toluidine salts resulting: thus with the hydrochloride



$$\left.\begin{matrix}C_6H_5\\CH_3\\H\end{matrix}\right\}N,HCl = \left.\begin{matrix}C_6H_4,CH_3\\H\\H\end{matrix}\right\}N,HCl.$$

It is especially noteworthy that whilst paratoluidine (solid) results in the case of methyl aniline hydrochloride, a liquid toluidine, apparently metatoluidine, is formed when methyl aniline hydriodide is thus treated (HOFMANN).

Similarly, when the methyl iodide of dimethyl aniline (trimethyl phenylium iodide) is heated to a high temperature in a sealed vessel, or if dimethyl aniline hydrochloride is heated to 300° C. for ten hours with a large excess of methylic alcohol, analogous changes result; true homologues of aniline, or derivatives thereof, being formed by analogous reactions of "change of position." Thus with dimethyl aniline methyl iodide—



Dimethyl Aniline, Methyl iodide. — Dimethyl Toluidine, Hydriodide.

$$\left.\begin{matrix}C_6H_5\\CH_3\\CH_3\end{matrix}\right\}N,CH_3I = \left.\begin{matrix}C_6H_4.CH_3\\CH_3\\CH_3\end{matrix}\right\}N,HI =$$

Methyl Xylidine, Methyl iodide. — Cumidine, Hydriodide.

$$C_6H_3\left\{\begin{matrix}CH_3\\CH_3\end{matrix}\right.\left.\begin{matrix}\\\\CH_3\\H\end{matrix}\right\}N,HI = C_6H_2\left\{\begin{matrix}CH_3\\CH_3\\CH_3\end{matrix}\right.\left.\begin{matrix}\\\\\\H\\H\end{matrix}\right\}N,HI.$$

When the methylation of the resulting products is pushed further, as when the heating is effected in contact with excess of methylic alcohol, yet higher homologues are formed: thus there are formed successively derivatives of :—

Dimethyl aniline, $\left.\begin{matrix}C_6H_5\\(CH_3)_2\end{matrix}\right\}$ N;

Dimethyl toluidine, $\left.\begin{matrix}C_6H_4.CH_3\\(CH_3)_2\end{matrix}\right\}$ N;

Dimethyl xylidine, $\left.\begin{matrix}C_6H_3(CH_3)_2\\(CH_3)_2\end{matrix}\right\}$ N;

Dimethyl cumidine, $\left.\begin{matrix}C_6H_2(CH_3)_3\\(CH_3)_2\end{matrix}\right\}$ N;

Dimethyl cymidine, $\left.\begin{matrix}C_6H(CH_3)_4\\(CH_3)_2\end{matrix}\right\}$ N.

—HOFMANN and MARTIUS.

Amongst the products formed by the carrying out of this action to its limit is a hydrocarbon, apparently $C_6(CH_3)_6$; whilst a primary amine, $\left.\begin{matrix}C_6(CH_3)_5\\H_2\end{matrix}\right\}$ N, has been obtained in small quantity by HOFMANN amongst the bye products of the action of heat on trimethyl phenylium iodide.

The occurrence of these reactions has doubtless a most important bearing on the colour-producing properties of methyl aniline and dimethyl aniline. HOFMANN'S recent researches tend to show that the violet dye obtained by the oxidation of dimethyl aniline is *identical* with that got by methylating rosaniline, produced by oxidizing a *mixture of aniline and paratoluidine*.

Ethyl aniline, $\left.\begin{matrix}C_6H_5\\C_2H_5\\H\end{matrix}\right\}$ N.—This base is obtainable from aniline and ethyl iodide, &c., or from aniline hydrochloride and ethyl alcohol, in the same way as methyl aniline is prepared: it is a colourless liquid, boiling at 204° C. Notwithstanding the close connection between the dyes got by oxidizing methylated anilines and those by methylating rosaniline, ethyl aniline does not yield by oxidation any noteworthy quantity of dyes such as those got by ethylating rosaniline. The following bodies :—

Diethyl aniline, $\left.\begin{matrix}C_6H_5\\C_2H_5\\C_2H_5\end{matrix}\right\}$ N;

Amyl aniline, $\left.\begin{matrix}C_6H_5\\C_5H_{11}\\H\end{matrix}\right\}$ N;

Methyl toluidine, $\left.\begin{matrix}C_6H_4CH_3\\CH_3\\H\end{matrix}\right\}$ N;

Ethyl toluidine, $\left.\begin{matrix}C_6H_4CH_3\\C_2H_5\\H\end{matrix}\right\}$ N;

Diamyl aniline, $\left.\begin{matrix}C_6H_5\\C_5H_{11}\\C_5H_{11}\end{matrix}\right\}$ N;

Dimethyl toluidine, $\left.\begin{matrix}C_6H_4.CH_3\\CH_3\\CH_3\end{matrix}\right\}$ N;

and hosts of analogous substances are known, and attempts have been made to utilize some of them as colour-producing agents, but for the most part with little or no success. Methyl toluidine and dimethyl toluidine (both para- and meta-) probably occur in the mixture of methyl aniline and dimethyl aniline, which is now largely manufactured for the production of "Violet de Paris;" but they do not contribute to the improvement of the dye, and it is a great object to obtain an aniline free from higher homologues for this particular purpose. Aniline containing more than 5 per cent. of toluidine is unsuitable for the production of Violet de Paris (LAUTH).

Chloraniline, $\left.\begin{matrix}C_6H_4Cl\\H_2\end{matrix}\right\}$ N, and its homologues have been proposed as sources of colouring matters by POULAIN. When a mixture of chloraniline and chlorotoluidine is heated, hydrochloric acid and rosaniline are formed. The chlorinated bases are obtained, in the first instance, by acting on benzene with iodine and chlorine, when chlorobenzene is formed; this is then nitrated and converted into a chlorinated aniline oil in the usual way (*Vide article* BENZOL). By acting on these chlorinated bases with iodide of methyl, ethyl, &c., *methyl chloraniline*, $\left.\begin{matrix}C_6H_4Cl\\CH_3\\H\end{matrix}\right\}$ N, and analogous products are formed; and by the withdrawal of the elements of hydrochloric acid from these substances, or mixtures of them, other dyestuffs can be produced.

MANUFACTURE OF ANILINE OILS.

The various kinds of aniline oils (including in this term the commercial bodies sold as aniline, toluidine, xylidine, and their mixtures) are all prepared in the same way, the sole difference being in the nature of the nitrobenzol used, *i.e.*, in the character of the hydrocarbon or "benzol" used in the first instance.

The method first tried on the large scale (by Messrs. SIMPSON, MAULE, and NICHOLSON) was that of ZININ, viz., the action of sulphuretted hydrogen on the solution of nitrobenzol in ammoniacal alcohol. The alcoholic solution, placed in a digester furnished with a condensing worm, was first saturated with ammonia gas, and then sulphuretted hydrogen was led in to saturation; the temperature was then raised to 100° C. by a steam worm, the taps of the digester being closed, so that the pressure was considerable. In a few hours all odour of sulphuretted hydrogen disappeared, that of ammonia only remaining; the liquid was then cooled, and again saturated with sulphuretted hydrogen and heated to 100° C. When the reaction was completed (which was known by the perfect solubility in dilute hydrochloric acid of a small sample drawn from time to time as a test), the ammoniacal alcohol was distilled off and used over again, the aniline remaining in the still, mixed with sulphur from the decomposition of the sulphuretted hydrogen; thus, in the case of aniline :—

$$\underset{\text{Nitrobenzene.}}{C_6H_5.NO_2} + 3H_2S = \underset{\text{Aniline.}}{C_6H_5.NH_2} + 2H_2O + 3S$$

and similarly for the higher homologues.

The inconvenience of this method and its comparative costliness soon led to its abandonment; the same may also be said of the process invented by HOFMANN and worked for a time by E. KOPP, viz., the addition to nitrobenzol (contained in a still) of zinc (in lumps), and the gradual addition of slightly diluted hydrochloric acid, an agitator being kept in motion to promote the reaction; when the reduction was complete chalk was added to decompose the aniline salts formed, and the contents of the still submitted to distillation, a dull red heat being finally applied. The processes proposed by KREMER (action of 2 to 2½ parts of zinc dust, and 5 of water, on 1 of nitrobenzol, the action going on spontaneously when started by heating): VOHL (action of glucose and alkalies upon nitrobenzol): and WÖHLER (action of alkaline arsenites on nitrobenzol)—never came into very general use; the process of BÉCHAMP (the one now universally adopted) being much preferable for commercial purposes. The original mode of working was as follows (GIRARD and DE LAIRE):—Into cast-iron vessels 1 mètre high, 1·5 diameter, and 4 centimètres in thickness there is introduced a mixture of—

Iron filings,	200 kilogrammes.
Nitrobenzol,	100 "
Acetic acid at 40°,	100 "

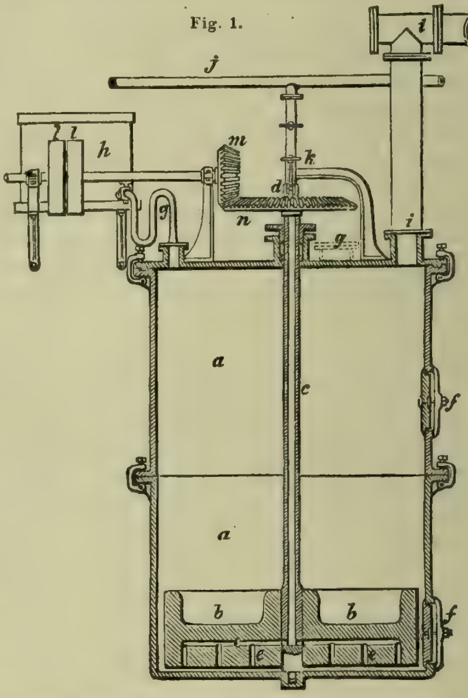
which fills the vessels about three-quarters full. These pots are covered by a dome furnished with a condenser, so that any products volatilized during the reaction may be recovered; an agitator moved by hand is provided to mix the ingredients. The iron being first introduced, the acetic acid is run in, and about a quarter of the nitrobenzol; in a few minutes a vigorous reaction begins and much vapour is evolved; this is partially condensed by the application of wet cloths to the dome, partly in the condensing worm. The rest of the nitrobenzol is similarly added from time to time as the reaction slackens; finally the whole is well mixed by means of the agitator, and a gentle heat applied to complete the reaction. On cooling a pasty mass results, which is removed and mixed with 10 to 12 per cent. of slacked lime; this mixture is then distilled in small retorts holding about 100 litres each, and provided with hand agitators to keep the mass from overheating at the sides. Aniline then passes over, its vaporization being much facilitated by the presence of acetone vapour, and the permanent gases arising from the decomposition of the calcium and ferrous acetates present.

This mode of operation presents several inconveniences; besides cost of fuel and labour, the aniline is largely contaminated with bodies of high boiling point (azobenzene, paraniline, xenylamine, acetanilide, &c.), either formed along with the aniline, or produced by its partial decomposition by the heat employed towards the end of the distillation; hence considerable modifications have been made in the process.

The following diagram (Fig. 1) illustrates the form of apparatus recommended by GIRARD and DE LAIRE ("Traité des Derivés de la Houille," Paris, 1873); the cylinder in which the reaction is carried out is made of dimensions suitable to the charges worked—for batches of 500 kilos. of nitrobenzol, it is made one mètre in diameter, and two in height. It is provided with two condensing worms, one so arranged that the condensed liquid drops back into the vessel (cohobating worm), one arranged as in ordinary distillation (condensing worm). The materials are agitated by steam power, the shaft of the agitator being hollow and connected with a steam pipe; the vanes of the agitator are likewise hollow and perforated with holes, in such a way that jets of steam can be injected into the vessel through the agitator itself.

The cast-iron cylinder is in two parts, *a* and *a′*, which are united together by flanges and screw-bolts; *b*, *b*, is the agitator; *c*, the hollow axle of agitator; *d*, a pipe leading steam from the steam-pipe, *j*, to the agitator; *e*, *e*, perforations in agitator through which the steam issues; *f*, *f*, manholes; *g*, *g′*, tubulations for introduction of the materials; *h*, reservoir of nitrobenzol communicating with the cylinder by a syphon pipe; *i*, exit tube for vapours, communicating with the cohobating and condensing worms, either of which can be brought into connection with the cylinder or disjoined from it by opening or closing a cock; *k*, screw-bolt arrangement connecting steam-pipe with hollow axle; *l*, *l*, pulleys; and *m*, *n*, cog-wheels communicating motion to the agitator.

Fig. 1.



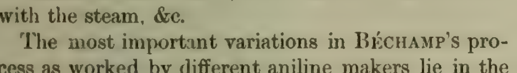
The whole of the nitrobenzol is first run into the cylinder together with the water and acid, and the iron filings are then added in batches of 50 kilos. each; a vigorous reaction ensues, and much vapour is evolved, which is condensed by the cohobating worm (the condensing worm being shut off); after the lapse of half an hour another batch of iron is introduced, and so on until the whole of the nitrobenzol is reduced, which is known by the perfect solubility in dilute hydrochloric acid of a sample drawn for the purpose. The cohobating worm is then shut off and the condensing worm connected; the slacked lime is then added through the tubulation for the purpose (*g*), and superheated steam (at 5 to 6 atmospheres) blown in through the agitator; the heat effects the reduction of the last traces of nitrobenzol, and when the cylinder is sufficiently hot, aniline and water are condensed in the worm. The former being only sparingly soluble in water is readily separable from the aqueous distillate; the small quantity of aniline dissolved in the latter is recovered by adding salt to the liquor, from which the aniline then separates, being much less soluble in brine than in plain water. The condensed water may also be used for generating steam for a second operation, whereby the dissolved aniline is also recovered. BOLLEY recommends the steam supply to be so managed, that about 14 parts of water condense for every 1 of aniline.

Various minor modifications in the shape and size of the aniline still, the kind of agitator used, &c., &c., have been adopted by different manufacturers. Thus many manufacturers dispense with a cohobating worm, using simply a still provided with an agitator through which steam can be injected at the close of the operation; the distillate which passes over during the first energetic action of the iron on the nitrobenzol is returned to the still, as it contains a good deal of unaltered nitrobenzol, which has been carried over with the steam, &c.

The most important variations in BÉCHAMP'S process as worked by different aniline makers lie in the relation between the quantities employed of nitrobenzol, acetic acid, and iron; if too much of the latter substance be used the reaction is apt to go too far, more hydrogen being added on than is required to form aniline, and ammonia and benzol being formed instead; thus with nitrobenzene itself;—

$$C_6H_5.NO_2 + 3H_2 = C_6H_5.NH_2 + 2H_2O$$
$$C_6H_5,NO_2 + 4H_2 = C_6H_6 + NH_3 + 2H_2O$$

and so on for the higher homologues. For this reason it is preferable to conduct the reducing process as above described (*i.e.*, to add the iron gradually to the whole of the nitrobenzol), rather than to do as some manufacturers do, viz., put all the iron into the still, and then add the nitrobenzol in small portions at a time. In the latter way of working, the nitrobenzol is always in contact with excess of iron. The presence of too much acetic acid gives rise to the production of acetanilide and its homologues,



$$C_6H_5,NO_2 + C_2H_3O,OH + 3H_2 = 3H_2O + \left.\begin{matrix}C_6H_5\\C_2H_3O\\H\end{matrix}\right\}N.$$

On the other hand, the presence of too little acetic acid and iron is favourable to the production of azobenzide from the deficiency in nascent hydrogen:—

$$2C_6H_5.NO_2 + 4H_2 = 4H_2O + C_{12}H_{10}N_2.$$

The most divergent statements are made by various writers as regards the proportions of iron filings, acetic acid, and nitrobenzol to be used in order to gain the best result; thus the following proportions have been given by the respective authorities named:

	Girard and De Laire (1873).	Bolley (1870).	Reimann (1867).	Kopp (1864).	Used by Renard and Franc in 1860. (Girard and De Laire).
Nitrobenzol,.....	100	100	100	100	100
Acetic acid,......	10- 2	5-10	50	90-100	100
Iron filings,......	140-140	200	150	140-150	200
Water,........ ..	50- 60	—	—	—	—
Hydrochloric acid,	10	—	—	—	—

The following proportions are those actually employed in some large aniline factories with good results:—

(A)		(B)	
Nitrobenzol,.........100		Nitrobenzol,.........	13
Acetic acid at 8° B (sp. gr. 1·06)	8	Acetic acid,..........	6
Iron,...,.............144		Iron filings,..........	15
		Water,..............	4

Of these proportions A corresponds more nearly with those given by GIRARD and DE LAIRE (1873), and B with those given by REIMANN (1867).

The yield of aniline oil necessarily varies with the nature of the nitrobenzol used; pure nitrobenzene should theoretically yield 75·6 per cent. of aniline; pure nitrotoluene, 78·1 per cent. of toluidine. In practice somewhat less than the theoretical amount is obtained, owing to the formation of bye products and to the presence of impurities in the nitrobenzol, &c.; something like 66 parts of aniline oil per 100 of nitrobenzol is a fair average yield. KREMER'S process (see *ante*) yields about 65 parts from 100 of good nitrobenzol, if properly conducted.

It was formerly supposed that the reduction of nitrobenzol to aniline occurred in virtue of the reaction—

$$C_6H_5,NO_2 + 2\,Fe + H_2O = Fe_2O_3 + C_6H_5,NH_2$$

peroxide of iron being formed; but SPILLER has recently shown (British Association Reports, 1873) that magnetic oxide of iron is produced, thus:—

$$4C_6H_5,NO_2 + 9\,Fe + 4H_2O = 3F_3O_4 + 4C_6H_5,NH_2$$

The crude aniline oil is next subjected to a process of fractional distillation; the lowest portions of distillate frequently contain benzene and its homologues, acetone, odorine, &c., &c. Usually the oils are purified by the colour maker himself, that he may obtain the particular mixtures he prefers. In some cases, however, the oils are prepared for the market according to contracts, specifying the proportion of the substance that shall distil between certain fixed limits. Light aniline oils distil for the most part below, and heavy aniline oils chiefly above 200° C. The term *queues d'aniline* (aniline tailings) is applied to the highest boiling heavy oils.

REIMANN distinguishes the light and heavy oils by the names *kuphaniline* and *baraniline* respectively, and gives the following tables as to the composition of various kinds of commercial oils:—

	Kuphaniline.	Baraniline.
	Per cent.	Per cent.
Water, odorine, &c.,...........	5	—
Aniline,......................	90	—
Toluidine (para- and meta-),.....	5	70
Higher homologues,............	—	30
	100	100

Distinguishing these by the letters K and B respectively, the following results are found, as the result of carefully conducted experiments made by that chemist:—

Distilling below Degrees C.	Mixtures Containing—										
	K = 100 B = 0	K = 90 B = 10	K = 85 B = 15	K = 80 B = 20	K = 75 B = 25	K = 62·5 B = 37·5	K = 60 B = 40	K = 50 B = 50	K = 37·5 B = 62·5	K = 25 B = 75	K = 0 B = 100
180°	2·5	7	2·5	5·5	3·5	4	—	4	2	3	—
—	6	—	—	22	3·5	3	—	3	2	2·5	—
185°	54	50	29·5	—	5·5	2·5	7	4·5	—	2·5	—
—	—	—	—	—	—	—	—	—	—	—	2
190°	34	34	56·5	55·5	55·5	41	37	7·5	5·5	4·5	1·5
195°	—	5	7·5	8·5	15	25	33	42	40	17	8
200°	—	—	—	—	9	8·5	—	19	28·5	36	18
205°	—	—	—	—	4·5	5	16	10	11	16	39
210°	—	—	—	—	—	4·5	—	3·5	7·5	8	19
215°	—	—	—	—	—	—	—	—	—	4·5	7
Residue,	3·5	4	4	8·5	3·5	6·5	7	6·5	3·5	5	5·5

The kind of oil most suitable for making fuchsine is that containing 75 per cent. of kuphaniline and 25 baraniline, *i.e.*, of which 92 per cent. distils below 200° and 68° below 190°.

The following apparatus is described by Girard and De Laire for the fractional distillation of crude aniline oils ("Traité des Derivés de la Houille," Paris, 1873) (Aniline, Plate 1.):—A distilling vessel provided with two necks, and having a capacity of about a cubic mètre, is heated by a fire; the aniline vapour issuing from the neck is made to traverse a series of condensing tubes immersed in a tank of aniline oil, so arranged that what is condensed in these worms returns to the still: the lowest boiling substance, not being wholly condensed, passes on to another condensing worm, and is thus separated. The aniline oil in the tank becomes heated and begins to distil also, the tank being provided with a separate condensing worm.

In the accompanying engraving (Aniline, Plate 1.) *a c* is the neck of the still communicating with the sinuous condensing tube *k*; *b e*, a second neck, for reflux of liquid condensed in *k*; *d d*, a tube connecting the tank *i* with its condenser *o*; *f f*, a tube connecting the sinuous tube *k*, with its condenser *n*; *g*, a two-necked still; *h*, manhole; *i*, a tank for the second batch of aniline, to be distilled by means of the heat given out by the condensation of vapours in the sinuous tube *k*; *j*, the reflux tube; *l*, tap for emptying still; *m m*, thermometers; *n*, condensing worm for vapour from the still *g*; *o*, condensing worm for vapour from tank *i*.

By means of an arrangement such as the foregoing it is easy to separate a crude oil into fractions possessing a composition approaching to the following:—

LIGHT ANILINE OILS.

Percentage,...........	3·7	34·2	53·7	7·1	1·3
Distilling at °C,....	below 180°	180° to 185°	185° to 190°	190° to 195°	above 195°

HEAVY ANILINE OILS.

Percentage,...........	10	20	40	22	8
Distilling at °C,....	below 195°	195° to 200°	200° to 205°	205° to 210°	above 210°

Aniline Tailings.

Very little aniline, a little toluidine, xylidine, cumidine, &c., together with bye products such as phenylene diamine, paraniline, xenylamine, azobenzide, acetaniline, and other homologues, &c.

Krouber gives the following valuable tables illustrating the general characters of the benzols, nitrobenzols, anilines, and fuchsines, derivable the one from the other:—

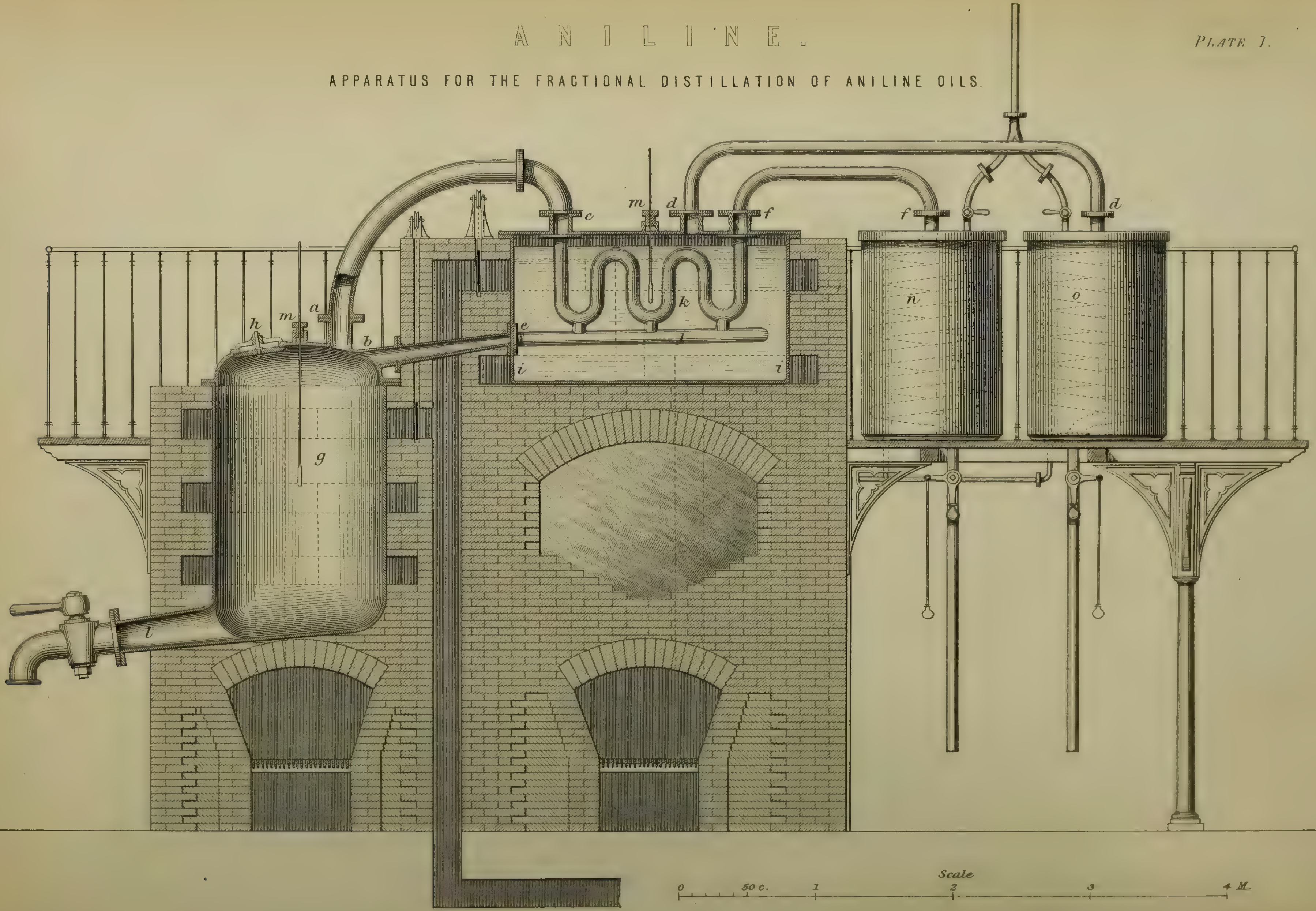
	Boiling point of Benzol.	Sp. gr. of Benzol at 15°.	Principal boiling point of Nitro-benzol.	Sp. gr. of Nitrobenzol at 16°.	Yield of Aniline Oil per 100 parts of Nitrobenzol.	Principal boiling point of Aniline Oil.	Sp. gr. of Aniline Oil at 16°.	Yield of Colour obtainable, Crystallizable Fuchsine being taken as 1000.	Tint of Colour communicated to Goods dyed therewith.	
	Degrees C.		Degrees C.			Degrees C.				
a	83–84	0·9118	205–210	1·1591	59	180–185	1·0205	5	Dirty violet.	Contains chiefly violaniline.
b	80–85	0·9263	205–210	1·1617	55	180–185	1·0199	20	Reddish violet.	
c	85–90	0·9154	210–215	1·1577	56	185–190	1·0181	110	Violet red....	Mauvaniline with a little rosaniline.
d	90–95	0·9210	210–215	1·1445	63	185–190	1·0139	160	Red.	
e	95–100	0·9089	215–220	1·1425	66	190–195	1·0109	230	Red.	
f	100–105	0·9071	220–225	1·1365	73	195–200	1·0060	270	Red.	
g	105–110	0·9048	220–225	1·1319	74	195–200	1·0018	240	Red.	
h	110–115	0·9033	225–230	1·1235	69	200–205	1·0009	260	Red..........	Contains much chrysotoluidine.
i	115–120	0·9022	225–230	1·1187	74	200–205	0·9975	260	Yellowish red..	
j	120–125	0·9009	230–235	1·1182	73	205–210	0·9943	200	Red.	
k	125–130	0·9001	230–235	1·1093	74	205–210	0·9926	180	Red.	

The benzol marked *a* was crystallizable. The nitrobenzols and anilines derived from these benzols yielded the following quantities of distillates at the various temperatures indicated:—

ANILINE.

PLATE I.

APPARATUS FOR THE FRACTIONAL DISTILLATION OF ANILINE OILS.



J. B. LIPPINCOTT & CO. PHILADELPHIA.

Nitrobenzol from Benzol marked	Range of Temperatures. Degrees C.												Total Distillate.
	195° 200°	200° 205°	205° 210°	210° 215°	215° 220°	220° 225°	225° 230°	230° 235°	235° 240°	240° 245°	245° 250°	250° 255°	
a	2	3	93	2	—	—	—	—	—	—	—	—	100
b	—	—	52	40	7	1	—	—	—	—	—	—	100
c	—	—	11	64	13	9	3	—	—	—	—	—	100
d	—	3	5	52	32	7	1	—	—	—	—	—	100
e	—	2	2	11	58	15	11	1	—	—	—	—	100
f	—	—	3	4	28	43	16	5	1	—	—	—	100
g	—	—	1	3	4	48	31	11	2	—	—	—	100
h	—	—	1	3	4	18	51	18	4	1	—	—	100
i	—	—	—	2	2	6	41	34	11	4	—	—	100
j	—	—	—	2	2	6	24	40	13	9	4	—	100
k	—	—	—	1	3	3	10	37	29	13	3	1	100

Aniline from Benzol marked	Range of Temperatures. Degrees C.										Total Distillate.
	Below 180°	180° 185°	185° 190°	190° 195°	195° 200°	200° 205°	205° 210°	210° 215°	215° 220°	220° 225°	
a	5	92	3	—	—	—	—	—	—	—	100
b	4	78	14	4	—	—	—	—	—	—	100
c	3	28	61	8	—	—	—	—	—	—	100
d	—	5	60	29	6	—	—	—	—	—	100
e	—	4	9	64	16	7	—	—	—	—	100
f	—	—	4	38	46	8	4	—	—	—	100
g	—	—	—	5	54	29	8	4	—	—	100
h	—	—	—	4	32	53	7	4	—	—	100
i	—	—	—	—	5	62	24	6	3	—	100
j	—	—	—	—	4	25	50	15	6	—	100
k	—	—	—	—	—	6	52	29	8	5	100

With various mixtures of the foregoing benzols, &c., KROUBER obtained the following results:—

Mixtures of Aniline from Benzols marked (equal quantities of each kind of Aniline)	Boiling points of Benzols used.	Relative quantities of Colour produced.	Shades of Colour communicated to Goods dyed therewith.
	Degrees C.		
b + *c*	80–90	16	Very violet red (mauvaniline and rosaniline).
d + *e*	90–100	17	Red.
f + *g*	100–110	32	Red.
h + *i*	110–120	24	Yellowish red (rosaniline and chrysotoluidine).
j + *k*	120–130	18	Red.
b + *c* + *d* + *e*	80–100	24	Violet red.
d + *e* + *f* + *g*	90–110	37	Red.
f + *g* + *h* + *i*	100–120	31	Red.
h + *i* + *j* + *k*	110–130	19	Red.
b + *c* + *d* + *e* + *f* + *g* + *h* + *i* + *j* + *k*	80–130	25	Red.

The best results, therefore, are obtained when a benzol boiling principally between 90° and 100° C. is used, giving an aniline boiling for the most part between 185° and 205° C. This result differs but slightly from REIMANN'S (see *ante*), the best oil for fuchsine being stated by him to boil 61 per cent. between 185° and 190° C., and 28·5 per cent. between 190° and 205° C. GIRARD and DE LAIRE state that the most suitable oil is that composed of sensibly equal quantities of true aniline and toluidine, and boiling 10 per cent. between 182° and 185° C., 40 per cent. between 185° and 190° C., 40 per cent. between 190° and 195° C., and 10 per cent. between 195° and 200° C. KOPP states that the best fuchsine oils are found to boil almost wholly between 185° and 210° C.; whilst HOFMANN found that various specimens of the oils actually in use on the large scale boiled between 182° and 220° C.

MANUFACTURE OF DIPHENYLAMINE.

The apparatus employed by GIRARD and DE LAIRE is described by them as follows ("Traité des Derivés de la Houille," Paris, 1873):—

An autoclave of malleable iron 0·6 mètre diameter and 0·8 mètre in height is provided, the interior being enamelled. To the lid are affixed a safety valve, a metallic pressure gauge, and an iron tube closed at the bottom and dipping inwards in such a manner that the end of the tube is below the surface of the liquid in the autoclave; in this is placed a thermometer.* A condensing tube which can be shut off at pleasure by means of a cock is also adopted, so that the interior can be brought into free communication with the external air without the loss of volatile substances. The heat is communicated by a flue proceeding from a coke furnace, the draught of which is regulated by dampers; the direct action of the fire is thus avoided, only the hot products of combustion being used for heating the autoclave. The annexed diagram (Fig. 2,) illustrates the nature of the apparatus. A cohobator is there represented as also attached to the autoclave; this can be shut off at pleasure by means of a cock; it communicates with a cylindrical condensing vessel immersed in water, the purpose of which is to regain ammonia liberated during the reaction: 70 kilos. of perfectly dry aniline hydrochloride, and 50 of aniline are introduced into the autoclave and the fire raised; the thermometer quickly mounts up to 200° C., the pressure gauge indicating no excess of pressure. After this point is reached the thermometer rises only slowly, an increased pressure being noticed if all the taps are closed. It is found by experience that if the ammonia generated in the reaction be allowed to remain in the digester, the yield of diphenylamine is much less than if the ammonia be allowed to escape; in fact Girard and De Laire have found the inverse reaction to take place when a salt of ammonia, and one of diphenylamine, are heated together. In order to avoid this, the cohobator is opened so that the evolved ammonia may pass off into its appropriate condenser, the aniline being condensed and falling back into the digester. After about two hours the cohobator is shut off, the thermometer indicating a temperature of 215° or 220° C.; the heat being continued, the temperature gradually rises to 250° C., whilst the pcessure mounts up to 5 atmospheres. The whole operation lasts about twelve hours, from 60 to 77 per cent. of diphenylamine being obtained; if, however, the whole of the ammonia be retained in the autoclave, the yield does not exceed from 20 to 30 per cent.

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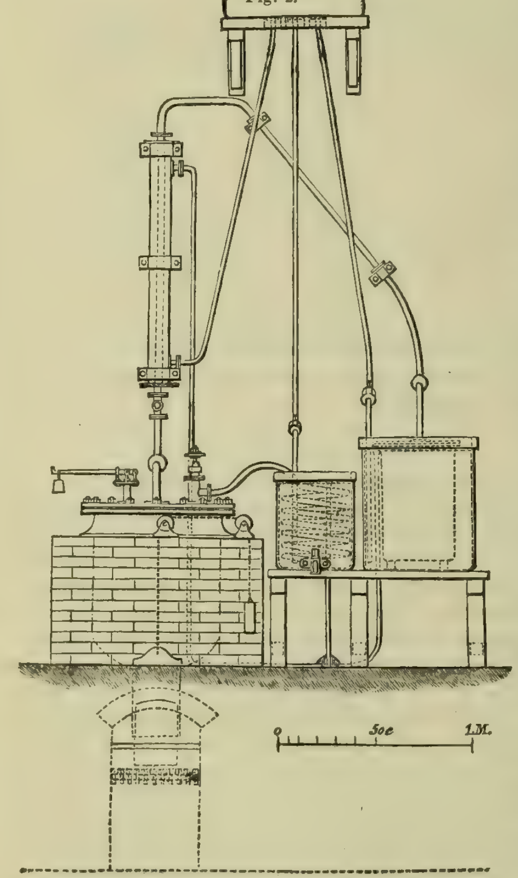
* The indications of the thermometer are more accurate, and the fluctuations of temperature are registered less slowly, if the tube is filled to the height of some inches with mercury.

Fig. 2.



The diphenylamine is separated from unaltered aniline by adding to the cooled product 70 kilos. of hydrochloric acid (which dissolves the whole), and next pouring it into 300 to 400 litres of water; diphenylamine then separates and falls to the bottom, whilst aniline hydrochloride remains dissolved. The precipitate is washed with a little boiling water and finally with an alkaline ley to decompose any residual diphenylamine hydrochloride, and is then either distilled in retorts with a large heating surface, or is recrystallized from petroleum oils. The aniline hydrochloride dissolved in the aqueous liquors is regained by evaporation, &c., and used over again.

The commercial diphenylamine thus obtained usually contains a considerable admixture of the higher homologues. A mixture of about 18 parts of diphenylamine and 11 of ditoluylamine produces a pure deep blue on oxidation by carbon sesquichloride.

MANUFACTURE OF METHYL ANILINE AND DIMETHYL ANILINE.

The process at first employed for the production of this body necessitated the use of iodide or bromide of methyl, and hence was far too costly to permit of any large development of the industry. Into an enamelled autoclave aniline is introduced, and then in successive portions the requisite quantity of methyl salt; much heat being generated during the mixture, it is necessary to add the methyl salt in such a way as to avoid any danger of mechanical projection. This is effected by employing a reservoir consisting of a tube with an expansion thereon, with a tap above and below the vessel thus formed; this is adapted to the lid of the autoclave. The top cock being open the methyl compound is poured in through a funnel; the top tap is then closed, and the lower one opened; the methyl salt thus flows gently into the autoclave, no projection being possible. This process is repeated until the requisite quantity of methyl salt is added; the autoclave is then heated to 100° C. for one or two hours. After cooling soda is added. and the liberated methyl aniline distilled off by steam.

Process of Bardy, Poirrier, and Chappat.—Fifty kilos. of pure aniline hydrochloride and 30 of methylic alcohol are introduced into an autoclave resembling that employed for the production of diphenylamine; the whole is then heated cautiously to between 250° and 300° C. for twelve hours. The reaction takes place for the most part at 280° C.; a sudden increase in pressure is frequently noticed, occasionally, it is stated, reaching 140 atmospheres. To avoid accidents, therefore, it is necessary to regulate the heat carefully, diminishing it greatly when the pressure begins to rise quickly, or even cooling the vessel. When the operation is completed, the product is treated with caustic soda ley, to decompose the hydrochlorides of methyl and dimethyl aniline formed; and these are then distilled off by steam, and rectified, if necessary, in an oil bath. Besides this mixture boiling near 200° C., other bodies of much higher boiling point are formed, such as dimethyl toluidine, dimethyl xylidine, &c. This mixture is used for Paris violet without any separation of the two constituents being attempted: the larger the quantity of methylic alcohol employed the greater is the quantity of dimethyl aniline present in the product, *cæteris paribus.*

Poirrier and Chappat state (Bull. Soc. Chim., Paris [2], vol. vi. p. 502) that by the action of heat on 100 parts of hydrochloride of aniline, and 50 to 80 parts of methylic alcohol, only three to four hours' treatment at 250° to 300° C. is required, the hydrochlorides being thus formed; whilst the action of 100 parts of aniline, 100 of sal ammoniac, and 50 to 80 of methylic alcohol at 300° C. requires several hours, and yields chiefly free methyl aniline. Nitric methyl ether (methyl nitrate) acts on aniline in the cold, but only slowly, producing methyl aniline; at 100° C. this action is rapid. Heating aniline with methylic alcoholic chloride (methyl chloride) at the ordinary pressure also forms methyl aniline. A larger or smaller quantity of dimethyl aniline is always formed simultaneously, according to the quantity of methyl compound used. These processes and corresponding ones for other substitution derivatives of aniline, are included in their patent (No. 71,970).

ANILINE DYES.

With the exception of mauveine, aniline black, and a few dyes not yet thoroughly investigated, all the aniline dyes in use are either derived from fuchsine or are closely connected with it. For convenience of reference, they may be grouped in accordance with their colour as follows:—

Red Dyes.—Fuchsine (also known under the name of Fuchsiacine, Chyraline, Azaleine, Erythrobenzene, Rosaniline, Pseudo-rosaniline, Aniline red, Magenta, Solferino, Roséine, Aniléine rouge, Fuchsinic acid, Rubine, &c., &c.); and several others of minor importance, such as Rouge de Toluene (Rosatoluidine, Toluene red), Rouge de Xylene (Xylidene red, Xyline red, Rosaxylidene), Chrysaniline red (Chrysotoluidine red), Geranosine, Saffranine, Furfurol red, Ulrich's scarlet, &c.

Blue Dyes.—Bleu de Lyons (Triphenyl rosaniline, Bleu de nuit, Bleu Lumiére, Bleuine, Girard and De Laire's blue, Night blue, Bleu de Paris, &c., &c.), Soluble blue (Nicholson's blue, Alkali blue), Diphenylamine blue; and several less well-known blues, such as Coupier's indigo blues, Rosatoluidine blues, Toluidine blue, Mulhouse blue, Azurine, Aldehyde blue, Azuline, Azodiphenyl blue, &c.

Violet Dyes and Dyes intermediate between Red and Blue.—Mauveine (Mauve, Aniline purple, Aniline violet, Perkin's violet, Aniléine, Phenameine, Violine, Rosolane, Tyraline, Harmaléine, Indisine, &c., &c.). Hofmann's violets, of various shades, Violet blue, Blue violet, Primula, &c., &c. Poirrier's and Chappat's violets or Violets de Paris (Methyl violets), of various shades; and several others of less importance, some of which are probably mixtures of reds and blues—Mono- and di- phenyl rosaniline (Violets de Lyons, Violet imperial, Dahlia, &c.), Regina purple (Nicholson's purple), Violaniline, Mauvaniline, Isopropyl violet, Turpentine violet (Britannia violet) Wise's violet, &c.

Green Dyes.—Iodine green or Hofmann's green, Methyl green (Vert de Paris, Vert soluble), Aldehyde green (Viridine, Aniline green), Perkin's green, Emeraldine. Mixed greens, usually mixtures of picric acid and blues or violets.

Miscellaneous Dyes.—Browns, yellows, oranges, greys, &c. Aniline black.

All the aniline dyes, with the exception of soluble blue (alkali blue), and a few analogous substances, are bases or compound ammonias. In many cases the base itself is colourless, its salts forming dyes of great intensity and beauty, such as rosaniline; what is used for dyeing, therefore, is uniformly a salt of the base. For some purposes the organic salts (the acetate, for instance), are preferred, for others salts of a mineral acid, *e.g.*, the hydrochloride. The nature of the tint communicated is usually only very slightly or not at all modified by varying the acid of the salt. Many of these bases in the free state are really hydrates (thus rosaniline = $C_{20}H_{19}N_3,H_2O$), the "water of hydration" being only lost by heating.

GENERAL HISTORY OF THE ANILINE DYES.

1. *Red Dyes. A. Fuchsine.*—In 1843 Hofmann observed that a red product is formed when aniline is treated with fuming nitric acid; Zinin also made the same observation at about the same time. In 1856 Natanson found that by acting on ethylene chloride with aniline at 200° C., a deep blood red colouring matter is formed; and at about the same time, Hofmann obtained a similar substance as one of the products formed by heating to 170° to 180° C. for thirty hours, a mixture of carbon tetrachloride and aniline. There appears to be little doubt that Natanson's and Hofmann's products are identical with fuchsine. The manufacture of *Hofmann's red* has been more than once attempted on the commercial scale, and a modification of it is employed by Girard and De Laire in the manufacture of diphenylamine blue. A committee of the Société de Mulhouse reported very favourably on the results of the process.

The technical use of red colours derived from aniline did not, however, commence till 1859, when Verguin formed a red dyestuff by the action of heat on a mixture of tin tetrachloride and commercial aniline oil. He immediately communicated his process to MM. Rénard Frères and Franc, of Lyons, who commenced manufacturing the dye forthwith, taking out a series of patents in France for the use of this and other metallic chlorides, and other substances. To this new colour the name *Fuchsine* was applied, according to one account in honour of the manufacturer (Rénard = Fuchs = Fox); according to another version, because of the resemblance in tint of silk dyed with this substance, to the flower of a variety of fuchsia plant (*Fuchsia codinea*). Other chemists soon found that many substances of a dehydrogenizing character formed fuchsine when heated with aniline oil; but the French law courts decided that the use of such other substances constituted an invasion of patent right, and in consequence the manufacture of fuchsine in France became virtually a monopoly. The product of the most important of these new processes (that proposed by Durand, Schlumberger, and also by Gerber-Keller, viz., the action of nitrates, more especially mercuric nitrate, on aniline oils) was termed *Azaléine.* Although almost identical in properties with fuchsine, it is in fact dissimilar, the one being a nitrate of a compound ammonia, the other the corresponding hydrochloride. The corresponding acetate is sometimes designated *Roseine*, this name having been originally applied to a red dyestuff obtained by oxidation of aniline with sulphuric acid and peroxide of lead (see *infra*).

The number of processes for the conversion of aniline oils into a red dye (presumably identical with fuchsine, though frequently called by another name) is very large; some of these were obtained as bye products in the manufacture of mauve.

Thus Laurent and Casthelaz prepared a red dye, termed by them *Erythrobenzol*, by acting on nitrobenzol with iron filings and hydrochloric acid, and heating the mass. Probably the colouring matter was identical with fuchsine, being formed by a double reaction, viz. :—First, the action of the metallic chloride on the aniline, analogous to that of the tin tetrachloride; and secondly, the reaction of nitrobenzol on aniline, in which fuchsine is also formed. This latter process has been several times patented since by other chemists, and quite recently by Meister Lucius and Brüning, who are now working it on a large scale. Schlumberger proposed the use of corrosive sublimate and tin amalgam; Depouilly and Lauth utilized the reaction of aniline nitrate on aniline (several patents involving this reaction have been subsequently taken out); Blockley, Watson, and other chemists employed aqua regia in some form as an oxidizing agent; Gingon used gaseous chlorine; Méne nitric acid; Jacquemin ferric sulphate; Williams used mercuric phosphate or acetate; Dale and Caro a mixture of lead nitrate and phosphoric acid; Smith used antimonic anhydride; Gratrix a nitrate of antimony (*i.e.*, a mixture of antimonic oxide and nitric acid) or nickel nitrate; others heated aniline salts either *per se* or in contact with sand (probably the oxygen of the air was here the oxidizing agent). Wilson heated aniline with 5 per cent. of arsenic, nitric, or iodic acid to 120° C., and then gradually added manganese dioxide; whilst recently Ferriere has obtained a red dyestuff by the action on aniline acetate of an ammoniacal copper solution; and Claus and also Hamel have obtained a similar product by heating aniline with sulphur chloride.

All these processes, however, and others too numerous to mention in detail, have been practically found inferior for commercial purposes to the method now in general use, viz., that patented almost simultaneously, in England by Medlock and by Nicholson, and in France by Girard and De Laire; *i.e.*, the use of arsenic acid as a dehydrogenizing agent.

Medlock's patent was dated January 18, 1860; Nicholson's, January 26, 1860 (both in Great Britain); Girard and De Laire's was dated May 26, 1860 (France). Arsenic acid, however, had been previously mentioned as a fuchsine-producing agent in a patent specification of Gerber-Keller in 1859, and had been described by Béchamp in the latter end of 1850. Poulain patented in 1869 the indirect oxidation of aniline and its homologues by means of chlorination and heating.

Various preparations are met with in the trade, designated as cerise, maroon, &c., which are mainly impure fuchsine; for the most part these are extracted from residues and bye products of the manufacture.

B. *Rouge de toluene*, and C. *Xylidine red*, were introduced by Coupier in 1866, and are as yet but little known.

D. *Chrysaniline and chrysotoluidine red.*

E. *Oxidation and decomposition products of rosaniline, geranosine.* F. *Saffranine.* G. *Ulrichs' scarlet*, patented in 1869. H. *Rosolic acid.*

I. *Furfurol red.*—Stenhouse found in 1860 that when aniline acetate and furfurol are well mixed together at the ordinary temperature, a red colouring matter is formed, insoluble in water, but soluble in alcohol, wood spirit, and strong acetic acid. Ammonia dissolves it to a colourless liquor, which is reddened again by acids. It dyes silks and woollens of a fine red tint, but it is very unstable, and cannot resist the action of light, and even fades when kept in the dark. Attempts were made to manufacture it by Persoz, but without success. Toluidine forms a similar product (Stenhouse—Proc. Roy. Soc., xviii. p. 537).

2. *Blue Dyes.*—A. *Various.*—Fritsche found in 1840 that when aqueous aniline salts are treated with hydrochloric acid and potassium chlorate, indigo blue flakes are precipitated; in 1860, Calvert, Lowe, and Clift, utilized a similar reaction for the preparation of a blue dye, called by them *Azurine*, by the action of weak soda or soap solutions on goods printed with emeraldine.

Caro found that blue products were formed by the reaction of nitrous acid on fuchsine, and the partial reduction of the products; and Lauth observed in 1860 that blue bodies result from the action of hydrogen dioxide on aniline salts, or of certain reducing agents, such as stannous chloride, on rosaniline salts. These substances are probably closely allied to the two following dyestuffs.

Mulhouse Blue and Aldehyde Blue.—The former of these was obtained in 1861 by Gros Renard and Schaeffer by boiling together rosaniline nitrate, powdered shellac, carbonate of soda, and aqueous alcohol; the latter in 1860 by Lauth, being produced when an aldehyde, or a mixture of materials that will generate aldehyde, is made to act on a hot acid solution of aniline. The want of permanency of these dyes has led to their almost entire disuse; although, unlike most aniline colours, they possess the power of adhering to cotton without mordanting.

The fugitive blue, or violet blue, formed by the action of hypochlorites on aniline (Runge's reaction), and various blues of a more or less purplish cast, formed by various inventors who endeavoured to imitate Perkin's mauve, are probably related to these substances; their industrial importance is small, and of their chemical composition nothing whatever is known, save that Runge's blue is closely allied to mauveine, as it gives rise to that substance on boiling with alcohol (Perkin). Guignon Marnas and Bonnet have prepared a blue aniline derivative, *Azuline*, by heating coralline (*q. v.*) with aniline.

B. *Phenyl and Toluyl Substitution Derivatives of Fuchsine.*—Soon after the publication of the arsenic acid process for making fuchsine, it was noticed that by the use of an insufficient quantity of acid (less than one equivalent for one of aniline) violet and even blue products were obtained instead of red. Thus, in 1861, Girard and De Laire patented the use of a mixture of 1 part acid and 1½ to 2 parts aniline for the production of violet and violet blue dyestuffs; in a later patent the action of aniline on a ready formed rosaniline salt was specified for the same purpose, the first product being a violet dye, which by further treatment gives a blue product. Similar patents were subsequently taken out by many chemists, in order to overcome certain practical difficulties in the way of obtaining a pure blue, which could not be obtained by the patented process of GIRARD and DE LAIRE, although every shade of violet could be readily obtained by that method. To effect this it is essential that either an *organic* rosaniline salt should be used, or else that an *organic* potassium or sodium salt should be also added. Thus MONNET and DURY, and also NICHOLSON, treated a mixture of rosaniline acetate (formed by adding free rosaniline to acetic acid) with aniline. GILBEE heated rosaniline with aniline acetate. PRICE proposed to heat fuchsine to 159° to 190° C. with aniline acetate, valerate, lactate, benzoate, tartrate, or oxalate, until the required shade is attained. PASSAVANT heated magenta with aniline and acetate of soda; the potassium salt gives a slight shade somewhat inclining to greenish, according to PRICE, and also LEVINSTEIN. WANKLYN, BOLLEY, and also HOLLIDAY, employed benzoic acid in the manufacture of aniline blue; C. G. WILLIAMS, oleate or oxalate of aniline. SCHLUMBERGER treated a mixture of fuchsine with aniline acetate and as much sodium carbonate as would just decompose the latter, and so on.

In working the process, many manufacturers heat a mixture of fuchsine, aniline, and sodium acetate until the colour becomes a blue violet or reddish blue, and then add to the mass benzoic acid, benzoate of potassium or sodium, sodium formate, stearic acid, sodium stearate, or common tallow soap, in small quantities at a time, until the proper shade appears; of these, soap is the substance most frequently employed.

The crude product obtained in the manufacture of aniline blue is (when freed from excess of aniline) frequently sold under the name of *Direct blue;* this again, when purified in various ways, is sold as *Purified blue* and *Night blue* (*Bleu Lumière*), the latter name being applied to such special varieties as communicate to goods dyed with them the power of retaining a pure blue tint by artificial light. This blue has been known by a variety of names, more especially as *Bleu de Lyons*, *Triphenyl rosaniline blue*, *Girard and De Laire's blue*, and *Aniline blue;* the term *Paris blue* (Bleu de Paris) has also been applied to it; but as this same term has been applied successively to nearly every other blue or violet blue invented, and is, moreover, often used on the Continent to indicate Prussian blue (ferric ferrocyanide), it is a name not to be recommended. A dye very similar to, if not identical with Bleu de Lyons, was also produced in 1866 by GIRARD and DE LAIRE by oxydizing commercial diphenylamine, containing diparatoluylamine, with any of the substances capable of use in manufacturing fuchsine, but preferably with sesquichloride of carbon; this is known as diphenylamine blue. A similar blue is produced from pure phenyl paratoluidine. Commercial diphenylamine blue is probably a mixture of various substances, the chief of which are also present in Bleu de Lyons. The blue dye of DELVAUX, prepared by heating rosaniline hydrochloride to 200–250° C., was probably very similar to or identical with Bleu de Lyons. COUPIER'S rosatoluidine blue also appears to be closely allied to Bleu de Lyons.

C. *Soluble Blue, Nicholson's Blue, Alkali Blue.*—NICHOLSON found, in 1862, that by treating Bleu de Lyons with sulphuric acid, and heating the mixture, a change was produced in the dyestuff, by which it was rendered readily soluble in water; the product possesses the properties of an acid, forming soluble alkaline salts possessed of much less colouring power than the free acid. Accordingly, in practice, this dye is used in a manner altogether different from those aniline dyes which consist of a compound ammonia united with some *acid*, such as hydrochloric or acetic acid; the slightly tinted *alkaline* solution of the dye (or rather of its alkaline salt) is used for dyeing, and the colour subsequently developed by passing the goods through an acid bath, when the acid itself is set free. Another soluble blue was prepared, in 1861, by PERSOZ DE LUYNES and SALVETAT, by heating together 9 parts chloride of tin, and 16 of aniline, to 180° C. for thirty hours.

D. *Azodiphenyl Blue.*—HOFMANN and GEYGER have recently obtained a blue dye by the action of aniline on azodiphenyl diamine.

3. *Violet Dyes and Dyes Intermediate between Red and Blue.*—A. *Mauveine.*—The production of this dyestuff from aniline by PERKIN, in 1856, is the era from which the manufacture of aniline colours actually dates: the oxidizing material employed by the discoverer was potassium dichromate, but it was soon found that many other oxidizing agents could give the same results. Of these the most satisfactory process appears to have been that patented in 1860 by DALE and CARO, viz., the reaction of chloride of copper (or a mixture of common salt and sulphate of copper) on an aniline salt.

DEPOUILLY and LAUTH, also COBLENTZ, used "bleaching" powder (BOLLEY, and also BEALE and KIRKHAM, had previously found that by adding chlorine water, or bleaching powder solution, to certain aniline salts, a blue liquor was obtained, becoming purple on standing and capable of dyeing silk without mordants). According to KOPP, the product of the action of bleaching powder on aniline invariably has a redder shade than that produced by means of bichromate. G. WILLIAMS employed permanganate solution, and thereby obtained not only a purple dye, but also a more soluble red one. D. PRICE employed boiling dilute sulphuric acid and peroxide of lead, obtaining three different shades, according to the relative quantity of the peroxide and the aniline used: *Violine*, with one equivalent of each; *Purpurine*, with two of aniline to one of peroxide; and *Roseine*, with one of aniline to two of peroxide—two equivalents of sulphuric acid being used in each case, and twenty times as much water as aniline.

KAY obtained a product, *Harmaline*, by the action of manganese dioxide and sulphuric acid on aniline. KOPP, STARK, and also SMITH prepared violet dyes by oxidizing an aniline salt with potassium ferricyanide, GRATRIX employed an aqueous solution of nitrate of copper; and LAUTH, in 1860, obtained a blue violet by means of binoxide of hydrogen. PHILLIPS used a mixture of bleaching powder and sulphate of iron. These and numerous other processes for the manufacture of violet dyes, with the exception of mauveine, have either never been adopted or have fallen into disuse.

B. *Hofmann's Violets.*—In 1863 Hofmann found that, by acting on fuchsine with methyl or ethyl iodide or bromide, dyes result of character analogous to Bleu de Lyons, but of not so blue a shade. Like the phenylated fuchsines, these dyes acquire progressively a bluer and bluer shade the further the methylation is carried, but even the final product (trimethyliodide of trimethyl fuchsine) is only a blue violet. Curiously enough, the body preceding this one in the list (dimethyliodide of trimethyl fuchsine) is a fine green; whilst all the others (methyliodide of trimethyl fuchsine, trimethyl fuchsine, dimethyl fuchsine, and methyl fuchsine) are of shades decreasing in blue cast and increasing in red shade, the nearer the body stands in the list to the original fuchsine. The dyes manufactured of this description are divided into three classes, viz., *Violet red* (*violet rouge*), marked R; *Violet blue* (*violet bleu*), marked B; and *Violet lumière*, marked B B. They chiefly consist of mixtures of methyl fuchsine and dimethyl fuchsine; dimethyl fuchsine and trimethyl fuchsine; and of nearly pure trimethyl fuchsine respectively (GIRARD and DE LAIRE). Similar mixtures of the corresponding ethyl derivatives also possess nearly the same tints, but are somewhat less blue.

The term "Lumière" is technically applied to these and other analogous dyes, in order to indicate their great purity of tint; even by artificial light the colour of goods dyed therewith remains the same: ordinarily the terms "violet lumière," "bleu lumière," mean not so much special chemical compounds, as mixtures so prepared as to possess the desired quality, *i.e.*, carefully freed from any constituents which could interfere with it.

Ethylic ethers, other than the iodides, chlorides, or bromides, also give rise to violet rosaniline derivatives (probably ethylated rosanilines); thus LEVINSTEIN has prepared a dyestuff under the name "Dorothea," by the reaction of nitric ether on rosaniline.

C. *Methyl Violets* (*Violet de Paris*).—The preparation of the alcoholic iodides required for Hofmann's dyes being difficult and costly, chiefly on account of the high price of iodine, attempts were speedily made to attain the same result (viz., methylated or ethylated fuchsines) by a cheaper process. LAUTH had found in 1861 that by the oxidation of methyl and ethyl aniline, dyes are obtainable of beautiful violet hues, but of not very permanent characters, the methyl aniline dyes being superior to those derived from ethyl aniline; but no practical application of this discovery was made until 1866, when BARDY succeeded in manufacturing methyl aniline, and dimethyl aniline, at a cheap rate by heating together aniline hydrochloride and methylic alcohol. The public taste in dyes having somewhat altered at this time, and colours that would stand exposure to light, &c., without alteration being no longer in exclusive demand, POIRRIER and CHAPPAT commenced the manufacture of violet and violet blue dyes, by the oxidation of the methyl aniline thus obtained.

The manufacture of these violets is now carried on to a large extent, and there seems reason for supposing that the trade will continue. There are certain differences noticeable between the two classes of dyes that in various cases lead to the preference of the one rather than the other, according to the taste or practical experience of the dyer. Recent experiments of HOFMANN ("Deut. Chem. Ges. Berichte, vi. 352) tend, however, to show that the products are chemically identical.

D. *Miscellaneous Violets and Mauves.*—These are for the most part formed by processes substantially the same as those by which these two main dyes are produced, the difference being in the nature of the body chosen to modify the rosaniline. Thus:—WANKLYN suggested the use of isopropyl iodide; PERKIN of nascent methyl and ethyl bromides produced by the action of heat on turpentine and bromide in presence of alcohol, and LAUTH and GRIMAUX the use of benzyl chloride. WISE obtained a violet by acting on fuchsine with valeric acid; KOPP heated tannate of fuchsine with wood spirit containing hydrochloric acid, thus probably obtaining HOFMANN'S methyl violet by the action of methyl chloride. SMITH heated fuchsine with salicylic acid, obtaining a fine violet; he also employed brominated acetone derivatives, forming an analogous colour.

The Regina purple or Nicholson purple, patented by NICHOLSON in 1862, was prepared by heating rosaniline salts to about 210° C., and has probably an analogous composition. DELVAUX obtained a somewhat similar substance, together with a red dyestuff, by heating aniline hydrochloride with sand to 200°–220° C.; the red product was soluble in water; the violet body being extracted from the residue by means of alcohol.

In 1867 GIRARD, DE LAIRE, and CHAPOTEAU, published the results of an investigation on the bye products of fuchsine-making; from these they extracted a violet and a mauve dye, termed by them respectively *violaniline* and *mauvaniline*. The same bodies give rise to various blue violets by operating on them with methyl iodide, &c., in the way that HOFMANN'S violets are made. Previously to the publication of these researches SCHNEIDER had found that a violet dyestuff is produced along with the "azaleine" prepared by means of mercuric nitrate; and PERSOZ, DE LUYNES, and SALVETAT had found a similar substance in the product of the action of tin tetrachloride on aniline; PARAF had also published a process for obtaining from fuchsine residues red, puce, and violet dyestuffs (Bull. Soc. Chem. Paris, [2] vii. 92.)

In 1865 a violet was sold under the name of Dahlia Imperial,* said to be obtained from fuchsine residues; it gave shades of great beauty, and commanded a high price. A similar dyestuff is obtained by the action of iodide of ethyl on mauveine.

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* The name Dahlia has also been applied to various other products.

STÆDELER, in 1866, found that perfectly pure aniline gives, on treatment with arsenic acid, a violet substance soluble in alcohol (Bull. Soc. Chim. Paris, [2] v. 225). A violet dye is also obtainable by the action of heat on a mixture of aniline hydrochloride and nitrobenzene, or by heating together at 180°–195° C. for from four to six hours, the following mixture:—Aniline (from benzol boiling constantly at 81·5° C.), 10 parts; nitric acid at 40° B, 3 parts; hydrochloric acid, 12 parts. Probably these products are all essentially violaniline. (COUPIER, *ibid.* vi. 500.)

By the action of nitrous acid on aniline, a product (azodiphenyl diamine) results, which, when phenylated, forms a blue or violet dyestuff, isomeric or identical with violaniline (HOFMANN and GEYGER). This reaction has not yet come into use as a trade process; the term "azodiphenyl" blue has, however, been applied to the product.

4. *Green Dyes.*—A. *Miscellaneous.*—It has been long known that certain aniline salts, especially the nitrate, turn green on the outside by exposure to air, probably by oxidation. WILLM found that when potassium chlorate is allowed to act on violet (mauveine?) made by DEPOUILLY and LAUTH'S process, a green precipitate is formed, and a liquid which communicates a green tint to wool dipped in it, and afterwards exposed to the air. BEALE and KIRKHAM also found that by the continued action of chlorine or of bleaching powder on an acid solution of aniline, a green was formed, probably by further oxidation of the violet first produced. In 1860 CALVERT, LOWE, and CLIFT attempted to utilize this reaction for colour printing, and termed the tint produced by the action of potassium chlorate on aniline salts, *Emeraldine:* this name has also been applied to aldehyde green.

Green colours were also made by mixing picric acid, or other yellow dyes, with aniline blues or purples; these mixtures, however, were unsatisfactory in tint by artificial light, looking dull and greyish. The picrates of triethyl rosaniline and trimethyl rosaniline have likewise been thus used to a considerable extent.

B. *Aldehyde Green* was first made in attempting to fix aldehyde blue: for this purpose CHERPIN made use of thiosulphate (hyposulphite) of sodium (it is said by the advice of a photographer who considered this agent the universal fixer). LUCIUS subsequently employed sulphuretted hydrogen solution, and then a solution of sulphurous acid to develop the green tint; USÈBE, sulphide (not polysulphide) of sodium; and HIRZEL sulphide of ammonium. SCHLUMBERGER prepared a similar dye by treating rosatoluidine, dissolved in sulphuric acid, with aldehyde.

C. *Iodine Green.*—During the manufacture of HOFMANN'S violets a green colour is sometimes produced along with the violet products; but until about 1865 this substance was not specially prepared or isolated. In that year WANKLYN patented a process for its production; FILLMANNS, and also MEISTER LUCIUS and BRÜNING, had, however, prepared it for the market previously to this. At first it was sold as a picric acid or tannin compound, nearly insoluble in water, and for dyeing purposes was dissolved in alcohol. Of late years the "iodine green" of commerce has been divided into several kinds; thus, instead of the picric acid compound, a zinc chloride compound has been prepared which is soluble in water. Frequently the dyestuff has been sold as liquid or as a paste readily soluble. In order to save the iodine the iodized body has also been converted into the corresponding chlorinated derivative, which dyes equally well.

D. *Methyl Green.*—This body is in all probability identical with "iodine green;" in any case it only differs from it in the same way that Violet de Paris differs from HOFMANN'S methyl violet. At first it was produced from Violet de Paris, just as iodine green itself was, viz., by heating with the iodide of methyl (ethyl isopropyl, amyl, &c., &c.), the green dye being essentially a dimethyl iodide of a trimethylated fuchsine; but latterly the use of methyl chloride has superseded that of methyl iodide. The green is sent out in crystals, solution, or a paste consisting either of dimethyl chloride of trimethyl fuchsine, or of the double chloride of zinc and this body, or of some such compound.

Perkin's Green is stated to be a magenta derivative, more closely resembling iodine green than aldehyde green, but differing from it in being more soluble, and also in being precipitable by means of carbonate of sodium: it is chiefly used for calico printing.

5. *Miscellaneous Dyes.* A. *Aniline Black.*—The various aniline blacks in use are not strictly speaking dyes; they are almost invariably produced during the process of colour printing, or by some subsequent treatment of the printed goods, and are not, like the true aniline dyes, in a state fit for immediate use by the dyer. Aniline black is in fact, at least in many instances, an intensely dark green.

In 1862 LIGHTFOOT printed fabrics with a mixture containing *inter alia* chlorate of potassium, an aniline salt, and copper chloride; by the reaction of these salts on each other, facilitated by exposure to air, black is developed. The copper salt, however, acted injuriously on the steam-printing rollers, and the mixture could not long be kept. Subsequent researches by LAUTH and others showed that though copper compounds are essential to the production of the colour, they need not be soluble; by substituting sulphide of copper for chloride the injurious action on the rollers is for the most part avoided. VERSMANN states that in order to prepare a good black, aniline as free as possible from higher homologues should be used, the purity of the shade being exactly proportionate to that of the aniline. The number of modifications of the processes of LIGHTFOOT and LAUTH is almost innumerable; each printer has his own pet formula. The general belief is that no good black can be formed without copper. KOECHLIN, however, states that the oxidation of a solution of aniline in hydrochloric acid by a mixture of potassium chlorate and ferricyanide yields a good black dye. He also recommends the use of tartrate of aniline mixed with sal ammoniac, in lieu of a mineral salt, such as the hydrochloride of aniline—injury to fabrics, mordants, &c., being thereby avoided. By the further action of bichromate of potassium on goods printed with aniline black, the purity of the black tint is much improved, and more solidity given. **Blumer Zweifel** states, that if an iron salt is substituted for a copper salt in the aniline black mixtures, a dark *indigo blue* is produced, and not a black at all. **Bolley** recommends this process for printing calicoes with indigo blue tints.

B. *Yellow and Orange Dyes.*—The chief of this class are the chrysaniline of **Hofmann** and the chrysotoluidine of **Girard**, **De Laire**, and **Chapoteau**; these are commercially known as "Phosphine," "Victoria orange," "Aniline orange," "Aniline yellow," &c., and are probably identical in the main, the orange shades being communicated by a slight admixture of fuchsine. They are extracted from the bye products of the fuchsine manufacture. Besides these are various dyestuffs of minor importance, such as *Zinaline*, obtained by **Vogel** by the action of nitrous acid on fuchsine, various yellows from the action of nitric acid on rosaniline and its homologues, and various yellows and oranges from the action of nitrous acid on aniline. **Scheurer-Kestner** prepared a yellow dyestuff by the action of tin and hydrochloric acid on mauveine. Oxidizing agents transform this body into a red product, and goods dyed with it become first orange and then red by exposure to air.

C. *Aniline Browns. Phenylene diamine Brown.*—By reducing dinitrobenzene, phenylene diamine results, and by acting on this with a nitrite a brown colouring matter results. It dyes silks and wools without mordants.

Wise's Brown.—Fuchsine and formic acid when heated together for some hours give an orange red colouring matter, which when heated with aniline becomes chestnut.

In addition to these, brown dyestuffs are obtained from leucaniline and chrysaniline; **Girard & De Laire**, **Sieberg**, **Jacobsen**, and others, have prepared brown dyestuffs by processes, descriptions of which are given further on.

D. *Aniline Greys.*—**Casthelaz** has prepared a grey dyestuff by acting on mauveine with sulphuric acid and aldehyde; other greys have also been described by **Block**, and also **Carver** and **Therault**.

MANUFACTURE OF ANILINE DYES.

The limits of the present article only permit a description of those processes which have been successfully worked on the large scale; and although chronologically the dye known as mauve or **Perkin's** violet comes first in order, it is more convenient to discuss the dyes according to their colours, beginning with fuchsine as the most important, firstly, on account of the large consumption of that dyestuff as such, and secondly, on account of its importance as the raw material in the manufacture of many other dyes.

Manufacture of Fuchsine.—**Verguin's** process was worked by MM. **Rénard Frères** and **Franc**, as follows, in accordance with their patent of April 8, 1859:—Into an enamelled iron pot holding some 20 kilos. were introduced 10 kilos. of aniline oil, and then 7 of tin tetrachloride, in small portions at a time, with constant stirring; the whole was then heated under a hood on a small fire until it boiled gently; the mass gradually darkened in colour, becoming deep red, and finally (in about half an hour) appearing almost black. When the required depth of shade was attained, the fluid was poured out upon cooling plates, where it solidified to a mass containing fuchsine corresponding to about 5 or 6 per cent. of rosaniline hydrochloride, aniline hydrochloride, salts of tin, and bye-products. Although the yield was small, the tint of this product was good; no purification was attempted, the crude melt being sent direct into the market under the name of fuchsine.

The azaleine of **Gerber-Keller** was prepared by heating together 10 parts of aniline, with 7 to 8 of finely powdered dry mercuric nitrate; the liquid became gradually red, the operation being interrupted when the mass began to thicken and emit yellow vapours. The whole was then poured into water, when the unaltered aniline floated to the top; the undissolved portion was again treated with water, and from the solutions thus obtained the dyestuff was thrown down by addition of common salt. A much larger yield was obtained than by **Verguin's** method; the mercury was almost wholly regained in the metallic state, whilst the nitric acid could also be recovered from the liquors. To avoid deflagration, and to obtain the best yield, **Gerber-Keller** recommends the operation being conducted on the water bath (*au bain-marie*); mercuric nitrate being added in small portions from time to time with constant stirring for 8 to 9 hours.

Another method is to heat a mixture of aniline and a highly concentrated solution of mercuric nitrate, free from excess of nitric acid, to 120° C. for from 10 to 18 hours. Metallic mercury sinks to the bottom; the resulting fluid is transferred to an iron still, and unaltered aniline distilled off by blowing steam through the liquor; the dyestuff is precipitated from the remaining solution by common salt, and then recrystallized.

The dyestuff made by means of mercuric nitrate is still in the market, though not in such large quantities as that made by means of arsenic. It is sometimes designated as *Rubine* or *Rubine imperial*, and being free from arsenic, is sold at a high price. Confectionery, sausages, wines, and liquors, are often tinted with it. The ordinary arsenical dye is sometimes used for these purposes, and traces of arsenic can often be detected in the substance thus coloured. The essential difference between azaleine or rubine and the fuchsine of **Verguin**, is that the latter is a hydrochloride, the former being a nitrate of the same base.

In an English patent taken out by **Perkin**, the mixture of aniline and mercuric sulphate or nitrate used is recommended to be heated to about 175° C.

Lauth and **Depouilly's** method depends on the action of heat (150°–160° C.) on a mixture of aniline nitrate, 1 part, and free aniline, from 6 to 8 parts; but it is somewhat difficult to avoid rise of temperature and consequent deflagration. The yield by this process is from 7 to 8 per cent. as a maximum, and the product is much more impure than that obtained by the preceding methods. From the crude melt a purified dyestuff is obtained, by boiling with twenty times its weight of water; unaltered aniline carrying fuchsine nitrate with it rises to the surface; this is skimmed off and filtered whilst hot through sand, and crude fuchsine nitrate is obtained on cooling as a greenish pasty mass with metallic lustre. Either benzol (boiling between 60° and 100° C.) or ether may be used to dissolve out the aniline, chrysaniline, mauvaniline, &c. The residue is cooled with caustic soda or potash ley, the aniline nitrate is decomposed, aniline being carried off by the steam. The mixture of bases (rosaniline, violaniline, &c.) is then treated with dilute hydrochloric acid, which takes up chiefly the rosaniline; on cooling the liquors deposit rosaniline hydrochloride.

Notwithstanding the considerable difficulties in the way of making this process work commercially, it has been from time to time revived and repatented with but slight modifications; thus HUGHES patented a method the same in principle—viz., heating together a mixture of aniline oil, 20 parts, and nitric acid of specific gravity 1·36, 6½ parts. After the water has distilled off, the materials are kept at 150°–200° C. for an hour, gently boiling; a dark red syrup is thus obtained, which is treated with water and soda to neutralize free acid, and then well washed to remove unaltered aniline nitrate.

In 1862 LAURENT and CASTHELAZ prepared *erythrobenzol* by mixing together 12 parts of nitrobenzol, 24 of iron filings, and 6 of ordinary hydrochloric acid, and allowing the mass to stand for 24 hours. The production of colour is much facilitated by heating the mixture. BOLLEY was unable to obtain any colouring matter by action in the cold. COUPIER has proposed a very similar method, consisting in the heating of a mixture of aniline ferrous chloride and nitrobenzol to 200° (see *infra*).

The carbon tetrachloride process was thus worked by MONNET and DURY:—A digester furnished with a safety valve and a thermometer was heated, first to 116°–118° C., by superheated steam, and finally to 170°–180° C. After cooling the mass was extracted whilst still warm, and boiled with water so as to get the dyestuff in solution. The proportions used were aniline oil, 4 parts, and carbon tetrachloride, 1 part. The yield is stated to be much superior to that obtained by means of tin chloride.

DELVAUX heated a mixture of dry aniline hydrochloride 100 parts, aniline oil 72 parts, and dry sand 1000 parts, to 110°–120° C. for 15 hours. On boiling the product with water, a large quantity of fuchsine is dissolved out as hydrochloride; the remainder can be extracted by alcohol, or by first boiling with an alkali and then with dilute hydrochloric acid. LAUTH has proposed a similar process for the preparation of Paris violet from methyl aniline.

SMITH'S antimony process is thus carried out: 6 parts of antimony are heated with 29 of pure nitric acid of sp. gr. 1·44, added in small portions, from half to three quarters of an hour being required for 3 kilos. of antimony. The vessels used are of earthenware, fixed inside cast-iron pans with Roman cement. The nitrous fumes given off are utilized for vitriol making. Constant stirring throughout the oxidation process is necessary; finally a white, very acid, and slightly damp powder is obtained. This is heated for 12 hours till dry, and is then calcined at a dull red heat in cast-iron vessels, in batches of 50 kilos., till all free nitric acid and moisture is driven off. A yellow powder of antimonic anhydride then results.

Eight vols. of aniline are mixed with nine of commercial hydrochloric acid of sp. gr. 1·165, and the whole evaporated on a sand bath till thick white vapours are evolved; it is very essential that no free acid should be here present. This can be readily effected by an exact neutralization of the acid by aniline; the point of neutrality being determined, not by the ordinary test papers, but by means of paper soaked in fuchsine solution. A violet or bluish tint is given to the paper by a trace of acid.

Twenty-five kilos. of dry aniline hydrochloride are charged into an earthenware conical pot, set in an iron pan heated to 240° C. by a paraffin bath. When thoroughly melted, 32 kilos. of antimonic anhydride are added in four batches, hour by hour with constant stirring. A tolerably energetic action is set up, but this soon subsides, and altogether ceases in from five to six hours. The "melt" is then ladled out by copper ladles and allowed to cool.

During the melting from 2½ to 3 kilos. of free aniline, and 2 to 2½ kilos. of water pass off; these are condensed by a head connected with a condensing worm, a draught being kept up by placing the free end of the worm in connection with a chimney.

The "melt" is powdered and mixed with 22½ kilos. of coarsely powdered soda crystals, and 30 litres of water; carbonic acid is disengaged. The whole is then heated to 80° C. for an hour with continual stirring, allowed to settle, the deposit strained on calico, and slightly washed with cold water. The moist solid mass is then heated with 300 litres of water in a copper boiler by means of steam. The solution, after settling, is filtered into crystallizing pans. The residue is again treated with 200 litres of water, and the liquor also filtered into crystallizing pans. The insoluble portion is boiled with another 100 litres of water, and the colour precipitated from the solution by common salt; and finally the residues are exhausted with water, and the liquors used, together with the mother liquors from the crystallizing pans, for the treatment of a fresh batch. When the impurities become so concentrated in the liquor that the dye will not crystallize properly, but requires to be precipitated by common salt, the antimony is regained from the insoluble residue by heating with carbonate of soda, common salt, and charcoal, in a specially constructed furnace. Two-thirds of the antimony used is thus regained in the metallic state. The yield of moist fuchsine obtained is about 7 to 7½ kilos., in certain cases as high as 12 to 12½ kilos., containing about half its weight of dry colour. Some varieties of aniline oil require more antimonic anhydride than others; thus, for some kinds equal weights suffice, whilst for others 25 parts of aniline hydrochloride require 35 of anhydride. (SIEBERG, *Dingler's Pol Journal*, clxxi. 366.) REIMANN states that this process is very long and inconvenient, and is, in fact, "of no value," as useful magenta cannot be made by its means; the manufacture of magenta in this way was, however, carried on by the inventor, in Glasgow, on a large scale for several years (several cwts. of aniline being worked up daily).

The reaction of nitrobenzol on aniline, or an aniline salt, appears to be commercially applicable as a means of producing fuchsine, though till recently it has not found much favour; certain metallic salts greatly facilitate the reaction. HOLLIDAY heated to 227° C. for several hours a mixture of aniline of high boiling point 2 parts, commercial hydrochloric acid 2 parts, and nitrobenzol about 1 part, and obtained a "melt" containing much fuchsine.

STAEDELER has published the results of several experiments on the reaction of nitrobenzene on aniline and toluidine, showing that blue, violet, and rose colouring matters are readily obtainable, according to the nature and proportions of the materials used and the heat employed in its duration

COUPIER has patented, amongst other processes, the heating together of the following mixtures for the production of rosatoluidine, rosaxylidine, and violaniline products respectively:—(1.) "Coupier's nitrotoluol" (a mixture of para- and meta- nitrotoluene), 95 parts; Coupier's toluidine (a mixture of para- and meta- toluidine), 67 parts; hydrochloric acid, 65 parts; and ferrous chloride, or an equivalent quantity of ferric chloride, 7 parts. (2.) Coupier's xylidine, 75 parts; and Coupier's nitroxylol, 105 parts.

SCHUTZENBERGER states that the dyestuff obtained by process (1) is identical with ordinary rosaniline, whilst the yield is as great, if not greater (*Jahresbericht*, 1869, 1162). GREIFF, on the other hand (*Ibid.* 1163), found that much resinous matter was formed, and also a large quantity of a dirty violet product.

LAUTH adds stannous chloride to a mixture of aniline and nitrobenzol, when an energetic action ensues. By adding boiling water when the tint becomes dark brown, a solution containing much fuchsine is obtained.

MEISTER LUCIUS and BRÜNING have recently revived the manufacture of fuchsine by the reaction of nitrobenzol on aniline, and are now sending into the market considerable quantities of fuchsine made in this way. Like the rubine prepared by means of mercuric nitrate, this dyestuff is *free from arsenic*, and hence is specially suitable for the artificial coloration of edible substances. Their process of manufacture is stated to differ from that of COUPIER in certain particulars, although based on the same principles.

MEDLOCK'S process for the manufacture of fuchsine is by heating 2 parts of aniline with 1 of "dry arsenic acid." His specification was so worded that his process, as actually patented, was practically valueless, and considerable litigation was the result. Arsenic anhydride, As_2O_5, appears to be, in fact, incapable of transforming aniline oil into fuchsine; in order to form this dyestuff it is essential that a hydrated oxide of arsenic should be present, *i.e.*, that the elements of water should be present, associated with those of arsenic anhydride, forming what is now spoken of as arsenic acid, *e.g.*, $As_2O_5.3H_2O$, or H_3AsO_4. A very concentrated aqueous solution of this substance is used, the excess of water being volatilized before the reaction is completed.

The arsenic acid was formerly prepared by acting on white arsenic (As_2O_3) with nitric acid. A cheaper process is to treat the arsenious oxide suspended in water, or preferably dissolved in hydrochloric acid, with chlorine; it is usually employed in the form of a syrupy liquid, containing from 70 to 75 per cent. of As_2O_5. The first method adopted was to heat a mixture of about 100 parts of aniline oil, and 150 to 160 of this acid (or a proportionally larger quantity of a weaker acid) in an iron pot, preferably enamelled internally, set either in a sand or hot-air bath, or better still, in an oil bath, and covered with a hood connected with a flue, to avoid injury to the workmen by the vapours evolved. The heat being gently raised with continual stirring, water was evolved, together with some aniline vapours; the mass gradually acquired a deep brownish red tint, becoming thicker and thicker, the temperature gradually rising to a point between 150° and 190°, too high a temperature being avoided as prejudicial to the yield and purity of the colouring matter. From time to time samples were drawn, and when these presented the right appearance, possessing after cooling a metallic bronzed tint, and breaking with a clean shining fracture, the heat was discontinued; the product (technically called the "melt") being ladled out on to iron plates to cool. When solid, the cakes were pulverized and then subjected to further treatment with solvents to extract the red colouring matter.

Numerous improvements and modifications have been made in this first rough process. In the first place, the aniline volatilized was a considerable source of loss; this was avoided by applying a cover and condensing worm to the pot. The next improvement was to use larger vessels, in which, by applying mechanical agitators moved by steam power, a much more uniform quality of product could be obtained. The ladling out of the "melt" while yet fluid, and the pulverization of the solidified mass, constantly exposed the workmen to the injurious action of the vapours; again, the presence of unaltered aniline in the "melt" is prejudicial to the effectual extraction of fuchsine, or, at least, lengthens the process, the final products (rosaniline salts) being less easily purified by crystallization in presence of aniline salts than in their absence. Besides these imperfections, it frequently happened that unsuitable aniline oils were employed, occasioning a great deficiency in the yield. Thus NICHOLSON and other manufacturers soon found practically that a body containing nearly 100 per cent. of pure aniline (*i.e.*, an oil made from a benzol boiling at 81° or thereabouts, and boiling at close upon 182° C.), was not the best material to operate on; an oil distilling for the most part between 185° and 200° C. being more suitable. Until Hofmann's researches had cleared up the composition of fuchsine, the *raison d'être* for this was unknown, although the fact was certain.

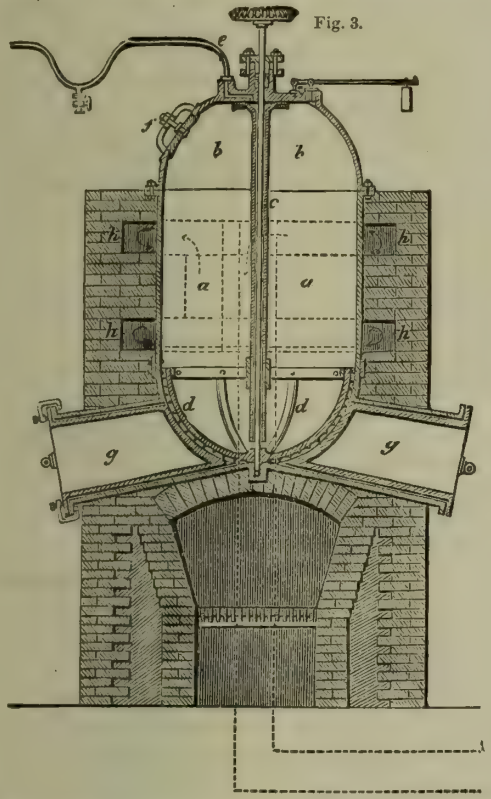


Fig. 3.

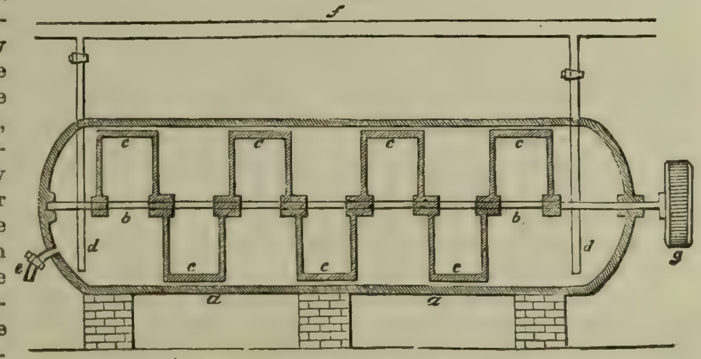
The improved method employed at the present day is thus described by Girard and De Laire. Into a retort holding about 2500 litres are introduced successively 800 kilos. of aniline oil (either prepared by partial fractional distillation of benzol, so as to produce directly a suitable aniline, or by mixture of various kinds of aniline oil, so as to obtain an oil of suitable composition), and 1366 kilos. of acid, containing 72 per cent. arsenic anhydride (this solution will not solidify even in the winter). An agitator moved by steam is provided, the axle of which is hollow, so that steam can be admitted to the bottom of the retort through the spindle of the agitator itself. In the base of the retort are two doors for withdrawing the finished charge, and at the top a safety valve, and a tap connected by a pipe with a tank of hot water. Fig. 3 indicates the general disposition of the apparatus:—*a*, *a*, the body of the retort; *b*, *b*, the dome; *c*, the hollow axle of the agitator; *d*, *d*, the serrated arms of agitator, to prevent the material from sticking to the bottom of the retort; *e*, the steam tube; *f*, the manhole; *g*, *g*, openings for withdrawing the charge; *h*, *h*, hot-air flues for heating the retort: these can be opened so as to cool the retort in case of necessity. The neck communicating with the condensing worm is on the other side of the apparatus, and is not shown in the section.

The retort is heated by hot-air flues, and is provided with a good condensing worm to condense the aniline and water that pass over; the temperature should not rise above 190°–200° C. In from eight to ten hours the operation is completed, the progress being judged by measuring the bulk of the condensed liquor. This should amount to about 850 litres, and after saturation with salt about 440 kilos. of aniline and 410 litres of water should be obtained. When 800 litres of distillate have passed, and the operation is nearly finished, the fire is withdrawn, the residual heat of the furnace being sufficient to finish the distillation of the unchanged aniline. To separate the last traces steam is blown through the "melt" in the still, which mechanically carries over the last portion of the aniline vapour. A small quantity of hot water is then run in, and then more in small quantities at a time; heat may be reapplied to the retort to facilitate the "hydration" process. At the end of about an hour a homogeneous fluid mass is obtained, which is run off through the openings into the solution-vats for the next operation.

By this process great economy in labour, fuel, and cost is effected; and in addition, the operation of pulverizing the cake of solidified melt is avoided, so that the workmen are in no way exposed to the chance of inhaling arsenical dust, or to the other painful consequences produced by the local action of solid arsenical matters (sores, ulcerations, &c.) Four men can thus work off 2000 kilos. of crude material per diem, and of these three are only required at the beginning and end of the operation; by the older processes ten men are required to turn out as much material.

In many factories, instead of admitting steam at the end of the operation to distil off the last traces of aniline, and running in hot water to avoid the production of a solid cake, the "melt" is run out on to cooling plates, placed under a hood to carry off the aniline vapour. The cake is then transferred to a boiler provided with an agitator, Fig. 4. *a*, *a*, is the

Fig. 4.



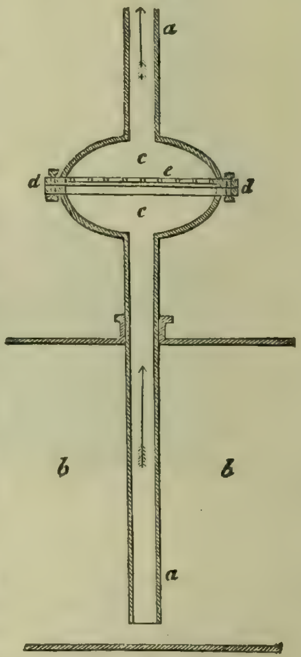
boiler set horizontally; *b*, *b*, is the spindle, and *c*, *c*, are the vanes of the agitator; *d*, *d*, the steam pipes for heating contents of boiler; *e*, the discharging cock; *f*, steam tube; and *g*, the cogwheel communicating motion to the agitator. When worked up with hot water (or other solvent) the dyestuff is extracted without necessitating a previous pulverization of the cake. Lixiviation, after the fashion of the alkali manufacture, is ineffective for fuchsine-making, the insoluble matter being of a viscid resinous nature. Great loss of dyestuff is occasioned by the mechanical covering up of its particles, unless a continuous agitation is kept up; even as it is, the insoluble residues left after treating the crude fuchsine often contain 3 to 4 per cent. of rosaniline.

As before stated, in the first days of fuchsine-making the crude melt was often sold to the dyer, who simply dissolved it in hot water, filtered, and used the liquor. A demand for a purified article, however, soon sprung up. At first the colour maker contented himself with simply extracting the soluble dyestuff with boiling water, filtering through beds of sand, and precipitating the clarified liquor with common salt in excess. A mixture of arseniate and hydrochloride insoluble in brine was thus thrown down. It was soon found that hydrochloric acid was a much better solvent than plain water. The liquors obtained by this means were precipitated by common salt, or by addition of just sufficient soda to saturate the acid and form brine, and the precipitate, consisting mainly of fuchsine hydrochloride, was redissolved and recrystallized; or they were precipitated by lime, soda, &c., in excess, and the precipitate dissolved up in some other acid (*e.g.*, nitric, oxalic, or acetic), and the corresponding salt thus formed was purified by crystallization. The arsenious chloride vapour evolved by the hydrochloric acid, and the aniline vapours thrown off by the action of the alkalies, were highly injurious to health.

Habedank proposed the following modification of the process for obtaining the hydrochloride (*Dingler's Pol. Journal*, clxxi. 73)—1 part of "melt" and 5 of water are used, and as much common salt as is equivalent to the arsenic acid originally employed; these are thoroughly boiled together, when rosaniline hydrochloride is formed, insoluble in the saline liquor containing sodium arsenite and arseniate. This liquor is run off and the resinous mass thoroughly boiled with water: an impure solution of rosaniline hydrochloride is obtained, filtered, and then allowed to crystallize, and the crystals purified by repeated crystallization. By this process the rosaniline arseniate and arsenite are converted into hydrochloride without the evolution of arsenical vapours.

The filtration of the liquors is best effected by means of the following device (Fig. 5)—ordinary filters are practically useless, as they rapidly become clogged by the viscid insoluble matter. A tube, *a*, *a*, dips down nearly to the bottom of the boiler, *b*, *b*; on this tube is a nearly spherical expansion, *c*, *c*, consisting of two concave iron vessels capable of being united together by a flange and screw bolts, *d*, *d*: between the mouths of these two vessels is strained a sheet of felt or other filtering material, a perforated iron plate, *e*, being fixed above to prevent rupture of the filter cloth. The boiler is so constructed that it can be made steam tight; when steam is admitted the pressure forces the liquid up the pipe, *a*, *a*, and through the filtering cloth upwards to a receiving tank. The tarry matters being thus left on the *under* side of the filter drop off by their own weight and fall back into the boiler. A set of these filters is so arranged that any one can be shut off, the hemispheres opened, and a new filter-cloth substituted for the old one without interfering with the action of the others. Differently shaped filters constructed on the same principles are frequently employed.

Fig. 5.



The liquid mass obtained by the improved process, or the crude "melt," is usually treated in one of the following ways, viz.: — (1) Boiling with hydrochloric acid, and precipitation of the dyestuff with sodium carbonate, as described below (chalk, limestone, or marble powder, may also be used instead of carbonate of soda). (2) Boiling with water alone, or preferably with water very feebly acidified with hydrochloric acid, and subsequent filtration and treatment of the filtrate with common salt. (3) Boiling with water and excess of lime, chalk, or soda. In each of these processes the boiling is best effected under pressure, time and labour being saved, and more concentrated solutions obtained.

For the first method the following proportions may be taken:—Solid "melt," or its equivalent of liquefied mass, 11 parts; hydrochloric acid, 2 parts; water, 33 parts. Steam is passed through for three or four hours, or until the residue becomes pulverulent and contains little or no red soluble matter; the liquor is then filtered and treated with sodium carbonate in quantity just equivalent to the sum of the arsenic and hydrochloric acids present. Rosaniline hydrochloride is precipitated, being insoluble in the resulting soda liquors, and floats to the top, being buoyed up by the carbon dioxide bubbles formed, and is skimmed off, dissolved in water by means of steam, and crystallized. The first crystals are redissolved in a boiler provided with an agitator, and the solution filtered and allowed to crystallize. The residue left on the filter consists for the most part of humus-like bye products along with mauvaniline, chrysotoluidine, and sometimes lakes formed by the presence of alumina in the sodium carbonate used. Violaniline is not present, its hydrochloride being practically insoluble.

The mother liquors arising from the recrystallization are often used over again in place of water, either to redissolve the first batch of crystals, or to treat the crude "melt." In this way the chrysotoluidine taken up together with the rosaniline is concentrated in the liquor (chrysotoluidine salts are more soluble than rosaniline salts in slightly acid solutions); and as one result the fuchsine made is apt to contain a little of this substance, giving it a scarlet shade. In some factories the mother liquors are precipitated by common salt, and the scarlet or crimson dyestuff thus thrown down (consisting of fuchsine more or less mixed with chrysotoluidine) is sold under the name of *Cerise*, *Scarlet Magenta*, &c., or is kept apart for the manufacture of certain dyestuffs made from impure fuchsine, *e.g.*, browns, greys, &c., &c.

For the second method, the following proportions may be used:—Crude fuchsine, 100 parts; hydrochloric acid, 1 part. Steam is blown through for four or five hours, and the resulting liquors filtered into large tanks: 120 parts of common salt is then added in small quantities, the liquid being agitated; the rosaniline hydrochloride thus thrown down is slightly washed and recrystallized as before.

For the third method, the one most generally adopted at the present day, the crude fuchsine is thoroughly boiled with an excess of lime, and a sufficient bulk of water to dissolve all the rosaniline present, for several hours: in case a "melt" has been used not previously freed from undecomposed aniline salts, the aniline is by this means liberated and expelled. Solid arseniate and arsenite of calcium are formed and separated by filtration while boiling hot; on cooling, a crop of crystals of impure rosaniline in the free state is obtained. The mother liquors may be used for the treatment of a fresh batch, or may be employed for the preparation of inferior qualities of dyestuff. It usually happens that a certain quantity of rosaniline is left in the lime mud; this is most completely extracted by treatment with dilute hydrochloric or sulphuric acid, and precipitation of the rosaniline solution by common salt. The first crystals of rosaniline may be purified by another crystallization from water; or they may be treated with twice their weight of alcohol, and the filtered solution distilled (mauvaniline is thus left undissolved, whilst the chrysotoluidine is only partially dissolved). Usually, however, these crystals are converted into some rosaniline salt, *e.g.*, the hydrochloride, and this salt purified by crystallization. A slight excess of acid being used, the chrysotoluidine is left in the mother liquors, whence it is sometimes extracted for sale under the names of Chrysaniline, Aniline yellow, Victoria orange, &c. Some manufacturers employ chalk, baryta, or soda in place of lime.

Yield of Rosaniline.—The amount of crystallized salt obtainable from a given quantity of aniline oil necessarily varies with the nature of the oil, and the way in which the manufacture is effected. By the improved process for fuchsine-making, coupled with the hydrochloric acid and carbonate of soda process for dissolving out and purifying the rosaniline hydrochloride, for every 100 parts of aniline originally employed from 25 to 30 parts of dry crystallized rosaniline hydrochloride can be obtained (GIRARD and DE LAIRE). According to REIMANN, 34 lbs. of magenta (rosaniline hydrochloride?) may be obtained from 1 to 2 cwts. of aniline oil of suitable composition. KLETZINSKY has, however, stated that from 100 parts of aniline and 200 of arsenic acid, 50 parts of pure crystallized red are obtainable (*Jahresbericht*, 1864, 820).

By the process of R. SMITH with antimonic anhydride, 100 parts of aniline oil yield from 30 to 50 of moist paste of colouring matter, containing half its weight of dry hydrochloride, from 10 to 12 parts of aniline being regained during the heating process by condensation of the vapours evolved (SIEBURG). This, therefore, represents a yield of between 17 and 29 parts of hydrochloride per 100 of aniline actually used. BOLLEY states that 40 per cent. of the weight of aniline used may be regarded as a very high yield of crystallized fuchsine, and 33 per cent. as an average amount. ROSENSTIEHL states that the yield of dry crystallized aniline red obtainable on the large scale averages from 27 to 30 parts per 100 of aniline used, whilst LEVINSTEIN estimated it at 20 parts; probably 28 per cent. may be taken as a fair average yield. The mercuric nitrate process is stated to yield, when properly conducted, quite as large an amount of crystallized fuchsine as is obtainable by means of arsenic acid under the most favourable circumstances. According to MONNET and DRURY, the yield of red dyestuff by the carbon tetrachloride process will compare favourably with that obtainable by any other method.

SCHUTZENBERGER states that by the reaction of aniline oil on commercial nitrobenzol a yield is obtained quite as great as that by means of arsenic acid, if not greater; COUPIER says that by this process a yield as high as 40 per cent. of crystallized colouring matter can be obtained, and that this dyes shades twice as dark as those given by an equal weight of ordinary commercial fuchsine.

Preparation of Rosaniline Salts.—As mentioned above, Azaleine and Rubine are virtually the nitrates of rosaniline. From the hydrochloride of rosaniline the free base is commercially prepared by dissolving the salt in a large bulk of boiling water, adding an excess of boiling alkaline solution, and continuing the boiling for some hours; the liquor is then filtered while hot into crystallizing vats, where the free base separates on cooling as nearly colourless crystals. Care must be taken that there is sufficient water present to retain the whole, or almost the whole, of the free rosaniline in solution; to avoid inconveniently large bulks of liquors, the solution is best effected under pressure.

To form the acetate, rosaniline is dissolved in boiling acetic acid, containing one-fifth as much glacial acid as there is used rosaniline, two and a half times as much water being also present. To obtain an easily crystallizable salt, glacial acid, free from sulphurous or sulphuric acid, should be employed; the rosaniline should be itself well crystallized, or at any rate prepared from a salt several times crystallized, and perfectly dry and in fine powder: it must be free from every trace of excess of fixed alkali used as precipitant. 100 parts of rosaniline are placed in an enamelled iron pan, and 20 of the glacial acid added little by little with continual stirring; the mass may be heated to 60° or 70° C. with advantage, but care must be taken that the acid does not distil over. When thoroughly incorporated, 240–250 parts of boiling water, free from calcareous salts, is rapidly added, the whole boiled a few minutes (but not long, otherwise the acetate is partially decomposed, an uncrystallizable basic salt being formed), and then run into crystallizing pans. After two or three days fine crystals are obtained, the weight of which is about equal to that of the rosaniline used.

It is possible to prepare the acetate by double decomposition of the sulphate, arseniate, &c., by lead acetate; but the resulting salt is less finely crystallized. The insoluble lead compound retains a considerable amount of colouring matter, and the yield is greatly diminished.

The sulphate of rosaniline may be prepared in the same way as the hydrochloride, substituting, however, sulphuric for hydrochloric acid if method No. 1 be used, or sulphate of soda for common salt if method No. 2 be employed; or it may be prepared by adding sulphuric acid in just the right quantity to the crude rosaniline prepared by method No. 3, and crystallizing the salt. In this case, or when the variation is adopted of adding the acid to the boiling solution of the base in lime or baryta water, the liquor must be kept hot by the injection of steam, and must be again filtered to separate sulphate of lime or baryta. The quantity of acid requisite is known by calculating the amount equivalent to the lime or baryta used in the boiling process.

The oxalate is prepared in precisely the same way from oxalic acid, and the lime water solution of rosaniline obtained by method No. 3, or prepared by heating a purified (recrystallized) aniline salt with lime in excess, and boiling with water under pressure.

Utilization of Fuchsine Residues.—In the preparation of fuchsine by the arsenic process, various kinds of residues and bye products are obtained, the nature of which vary with the modification of the process used. With the lime process (method No. 3) a mud is left consisting of the arseniate and arsenite of calcium,[*] humus-like decomposition products, violaniline, mauvaniline, &c., and mother liquors containing chrysotoluidine amongst other products. By the other two processes, an insoluble mass of hydrochlorides of violaniline, mauvaniline, &c., mixed with humus-like products, is formed, together with arsenical mother liquors.

Processes have been proposed for the recovery of arsenic from these residues, but as yet these methods have been but little employed. Thus Tabourin and Lemaire burnt the dried solid residues, leading the evolved gases through cooling pipes and chambers to condense the arsenic. The concentrated arsenical liquors were solidified by addition of quicklime, and the mass heated with carbon; the evolved arsenic vapours being burnt to white arsenic, and condensed as before. Weaker liquors were treated with milk of lime, and manganese chloride solution, to reduce arsenic acid to arsenious; the precipitated calcium arsenite was then treated as before.

Randu & Co. calcined the residues, collecting arsenious oxide in flues, &c.; or they calcined with coke dust, collecting metallic arsenic.

The arsenical liquors obtained by methods 1 and 2 are frequently evaporated until sodium chloride "salts out," for the most part in crystals. Nitric acid may then be added to oxidize arsenite present, and finally the resulting arseniate of soda crystallized, and sold to the calico-printer as "dunging salts."

Another method of treatment is to evaporate to a small bulk, and then distil with sulphuric acid. Chloride of arsenic passes over, and can be oxidized to arsenic acid by passing a current of chlorine gas through its aqueous solution.

Or again, the liquors are evaporated to a third of their volume; and as much sulphuric or hydrochloric acid added as corresponds to the neutral sodium arsenite present. Sodium sulphate or chloride crystallizes out, and from the filtrate an impure arsenic acid is regained, which may be used over again.

A better method of regaining the arsenic acid from these liquors is to add calcium chloride solution or milk of lime, or both, so as to obtain a precipitate of calcium arsenite and arseniate; this is then washed and treated with sulphuric acid, mixed with a little nitric. Sulphate of calcium is formed and free arsenic acid, the arsenious acid being reoxidized by the nitric acid. By evaporation and decanting from the gypsum deposited, a solution of arsenic acid is obtained, which may be used over again as a fuchsine-making agent. The lime or baryta mud obtained by method 3 may be directly treated in this way.

Mother liquors and weak liquors containing only a small quantity of colouring matter are most economically utilized by precipitating the colouring matter as a lake, which is then dried and sold as a pigment. Tannin, alumina, and stannic oxide form highly insoluble compounds with rosaniline, and are used for this purpose.

Manufacture of Violaniline, Mauvaniline, and Chrysotoluidine.—Though not red dyes, these bodies may be considered here, since they are obtained as bye products of the fuchsine manufacture. It usually happens that the fuchsine residue still contains rosaniline, from two to three hundredths being the usual amount with careful manufacture; but when the extraction process is not properly managed 4 or 5 per cent. may be left in the residue. The quantity of humus-like product formed depends much on the way in which the "melt" is manufactured. It seems to be formed chiefly at the expense of violaniline; if too high a temperature has been reached during the fusion (above 200° or 210° C.), other alteration or decomposition products are also formed. Thus at 213° C. rosaniline gives rise to a violet product, and violaniline and mauvaniline to dirty garnet-red bodies; the arsenic acid also oxidizes the bases somewhat further, giving rise to new coloured products. All of these are for the most part left in the residue, and alter injuriously the colour of the dyestuff thence extracted. It is practically found that, to obtain a good yield of fuchsine, the aniline oil should contain somewhat more aniline than that corresponding to the equation—

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[*] The latter salt usually contains but a small fraction of the total arsenic present, calcium arsenite being more soluble in water than the arseniate (Brinmeyr).

$$C_6H_5.NH_2 + 2(C_7H_7.NH_2) - 3H_2 = C_{20}H_{19}N_3.$$

The oil that distils over during the operation invariably contains still less toluidine, being frequently almost pure aniline. It is highly probable that the reason this excess of aniline is advantageous in the production of rosaniline, is that it renders the mass more fluid, and thus promotes the reaction, and helps to establish uniformity of temperature and to diminish the production of these alteration products.

In 1866 SOPP patented a process for the extraction of colouring matters from the resinous residues of the arsenic acid process. By treating 100 parts of residue with 70 to 80 of hydrochloric acid, washing with water, and treating the residue with nitric acid, a yellow colouring matter is obtained in the nitric acid solution, capable of crystallizing on cooling, or of forming a pasty precipitate on addition of water. The hydrochloric acid solution contains a little fuchsine, which can be extracted by precipitating the acid solution with soda and boiling the precipitate with water. The undissolved portion gives a fine deep red liquor on treatment with ammonia water, to which a little soap has been added. By treatment with hydrochloric acid, on the other hand, it gives a violet-blue fluid which dyes solid tints, but not shades of any great beauty; fabrics dyed therewith and passed through a solution of permanganate of potassium acquire a fine chestnut colour. In all probability the yellow product thus obtained is chrysotoluidine. The extraction of chrysaniline from fuchsine residues by various solvents had been practised by NICHOLSON several years previously.

In PARAF'S process (1867) the crude fuchsine residues are digested with muriatic acid (16 parts to 30 of residues), in the cold until nothing more appears to be taken up. By filtering and adding lime to the filtrate, so as to render it exactly neutral, a fine red colouring matter is thrown down. The insoluble portion is then heated with hydrochloric acid, when a violet and a puce substance dissolve out; by adding lime to the solution these dyes are precipitated as before, and can be collected for sale. By acting on these precipitates with strong sulphuric acid much dyestuff is dissolved. The solutions when freed from sulphurous acid by boiling communicate shades of great purity to wool and silk; the insoluble residues are used as lakes and pigments for wall papers, &c. The arseniate and arsenite of calcium formed during the extraction are sold as dunging material. Different manufacturers frequently pursue special methods of their own for working up and utilizing their residues; numerous products thus obtained find their way into the trade under various names; thus *Cerise* is an impure rosaniline containing small quantities of other substances which modify its tint, crystallizability, &c.

The following process for extracting violaniline, mauvaniline, and chrysotoluidine from the residues is given by GIRARD and DE LAIRE (*Traité des Derivés de la Houille;* Paris, 1873):—1000 kilos. of residues are boiled with 12,500 litres of water, containing 85 kilos. of ordinary hydrochloric acid. Violaniline is left undissolved, and is separated along with the humus-like products by filtration; to the filtrate is added 125 kilos. of hydrochloric acid. A precipitate, A, is formed, weighing about 40–45 kilos., and consisting mainly of mauvaniline and rosaniline hydrochlorides. To the filtrate from this precipitate 685 kilos. of common salt are added, when from 30 to 35 kilos. of a mixture, B, of mauvaniline and rosaniline salts is thrown down. To the mother liquors of this precipitate 83 kilos. of sodium carbonate at 59·8 per cent. Na_2O (*i.e.*, almost perfectly pure) are added; from 205 to 210 kilos. of precipitate C is obtained, consisting chiefly of rosaniline salt, with a little chrysotoluidine. Finally, 37½ kilos. of sodium carbonate are added to this filtrate, and a precipitate, D, weighing about 37 to 40 kilos., and consisting of little but chrysotoluidine is obtained.

Precipitate A is dried and left in contact for 24 hours with twice its weight of hydrochloric acid and 10 times its weight of water, the whole being stirred from time to time. After filtration the filtrate is precipitated by carbonate of soda, when, for every 100 kilos. of dry precipitate A, 32 kilos. of precipitate like A is thrown down; this is treated over again as A. The residue on the filter is treated twice successively with 1000 litres of a mixture of equal bulks water and hydrochloric acid, and a precipitate obtained from the liquid by adding 500 litres of cold water: in each case about 4 kilos. of nearly pure mauvaniline hydrochloride are thrown down. By addition of carbonate of soda to the mother liquors about 4 kilos. more mauvaniline are obtained, and by further saturation 4 kilos. of impure fuchsine. For each 100 parts of dry matter, A, there are obtained—Impure fuchsine, 4 per cent.; matter resembling A, 32 per cent.; mauvaniline, 12 per cent.; residue insoluble in acid and loss, 52 per cent. The mauvaniline hydrochloride precipitate is next dried and heated with benzol to dissolve out a little resinous matter, and is then cohobated with alcoholic potash; the free mauvaniline is then converted into any required salt, *e.g.* (such as the acetate, which yields an aqueous solution dyeing a magnificent mauve).

Precipitate B is either sold as "violet fuchsine," and used directly for dyeing, or is treated as A, but with acid containing only one-fifth of hydrochloric acid instead of one-half: it is thus separated into mauvaniline and rosaniline.

Precipitate C is dissolved in 2000 litres of water, containing 5 kilos. of hydrochloric acid per 100 kilos. of precipitate; the solution is filtered into a crystallizing pan, when from 25 to 30 kilos. of pure rosaniline hydrochloride are deposited. The mother liquors contain the chrysotoluidine and are used over again in the same way; after which common salt is added, and a precipitate resembling C is obtained (and treated as C), the brine yielding a precipitate of impure chrysotoluidine by addition of carbonate of soda. This is treated with precipitate D.

Precipitate D.—100 kilos. of this precipitate are dissolved in 2500 litres of lime water, containing a little lime in suspension. After boiling for three or four hours the liquor is filtered into a vat of dilute hydrochloric acid (sulphuric acid may be employed, but not so advantageously). On cooling, crystals of "yellow fuchsine," or rosaniline mixed with a little chrysotoluidine, are deposited. The portion insoluble in lime water is heated in an enamelled digester with a little water, and enough hydrochloric acid to neutralize the lime; the chrysotoluidine melts, agglomerates, floats on the liquid, and is removed by skimming. To separate the last traces of rosaniline, 100 kilos. of skimmings are dissolved in 2000 litres of boiling water, acidulated with 100 kilos. of hydrochloric acid; 10 kilos. of zinc are then added, and the whole boiled for eight hours. The rosaniline is thus reduced to leucaniline, which is not so easily precipitated by common salt; the filtered liquor is treated with salt (20 kilos.) and a little sodium carbonate to neutralize the acid, when 80 kilos. of amorphous chrysotoluidine are thrown down. This is again dissolved in 2000 litres of slightly acidulated water, filtered, and precipitated with 50 kilos. of caustic soda ley of 12° B. The precipitate is washed with cold water, and boiled for two hours with 2000 litres of hot water and 8 kilos. of sulphuric acid; the cooled liquor is partially precipitated with carbonate of soda. 20 kilos. of chestnut-brown-yellow precipitate are obtained. By further addition of common salt, 25 kilos. of pure yellow chrysotoluidine are thrown down; which is transformed into sulphate by treating with exactly the necessary quantity of sulphuric acid. 100 kilos. of dry precipitate D yield a chestnut-yellow dyestuff suitable for leather, &c., 20 per cent.; chrysotoluidine, 25 per cent.; the losses, chiefly as brown matters, are 55 per cent.

Rosaniline Mother liquors containing chrysotoluidine are worked up as follows, in order to separate it:—If acid, they are neutralized by carbonate of soda; common salt is then added, and the precipitated colouring matters are treated with zinc and hydrochloric acid as above, to convert rosaniline into leucaniline. Jacobsen states that "aniline orange" (chrysotoluidine?) may be obtained from the mother liquors of azaleine (mercury nitrate process) by precipitating the violet and brown dyestuffs by common salt, and crystallizing the filtrate.

Another process for the extraction of violaniline, mauvaniline, and chrysotoluidine from fuchsine residues, is to heat these (previously dried) with aniline to 100° C.; the bases are thus dissolved, and can be separated by filtration from the humus-like bye products. On neutralizing the aniline with an acid, violaniline is precipitated, the other two being retained in solution by the aniline salt formed. By means of common salt a precipitate of impure mauvaniline is thrown down, whilst the chrysotoluidine remains in solution, and can be separated by adding an alkali and distilling off the liberated aniline by means of steam.

It appears probable that considerable quantities of aniline bases might be obtained from fuchsine residues by simple dry distillation. By thus treating a resinous product of similar character, obtained as a bye product in the preparation of Hofmann's violet, and known accordingly as "Hofmann's gum," Spiller has recently obtained a large yield of methyl aniline or ethyl aniline, accordingly as ethyl or methyl violets were being made in the process of which the gum was a bye product. The gum is kept fused for some time, so as to drive off nearly the whole of the inclosed water, and is then heated in an iron still over a coke fire, either with or without the addition of roughly powdered charcoal. A mixture of pulverized iron borings, kaolin, and syrupy silicate of soda, forms an excellent lute for fixing on the head of the still, as it withstands a high temperature without softening. Small quantities of water and ammonia pass over together with a quantity of oily distillate, in quantity equal to half the weight of gum used. This distillate consists almost wholly of methyl- (or ethyl-) aniline. (Proc. Roy. Soc. xxi. 204.)

Manufacture of Rosatoluidine (*Rouge de toluène*).—Coupier patented in 1866 the following processes:—I. Coupier's toluidine (boiling at 198° to 202° C., and made from pure toluene separated by Coupier's fractionation process, *vide* Benzol) is mixed with 160 per cent. of its weight of arsenic acid containing 75 per cent of "real acid," and 25 per cent. of its weight of hydrochloric acid of commerce. The whole is quickly heated to 150° to 160° C. for three hours in a cast-iron still until the mass thickens, so that it can be drawn out into long brittle strings. The presence of hydrochloric acid is a new feature in this process, and also the low temperature employed; the mass is less likely to stick to the pot and be burnt, on account of the greater fluidity due to the excess of aqueous acid.

Process II.—67 parts Coupier's toluidine, 95 parts nitrotoluidine, from which the above is made; 65 parts commercial hydrochloric acid; 7 parts ferrous chloride, or its equivalent of ferric chloride. The above mixture is heated for three hours to 190° C. The addition of the iron salt greatly facilitates the reaction. The extraction of the colouring matter from the products is effected in the ordinary way adopted in the case of fuchsine.

Rosenstiehl found that the yield of crystallizable red dyestuff, from a mixture of 2 parts paratoluidine and 1 metatoluidine, by treatment with arsenic acid, was 39 per cent.; whilst a mixture of 2 parts metatoluidine and 1 of aniline gave the enormous yield of 50 per cent.—the yield from various mixtures of aniline and paratoluidine being in no case greater than 30 per cent. The maximum yield is obtained when equal weights of the two alkaloids are used. In all these cases the weight of bases regained by distillation is subtracted from the amount originally employed.

Coupier states that his toluidine, containing 95 per cent. of a mixture of para- and meta- toluidine, furnishes from 45 to 50 per cent. of crystallizable red, whilst any admixture lessens the yield. Roussille finds that the tinctorial power of rosatoluidine is 140, that of rosaniline being taken as 100 (*Bull. Soc. Chim.* Paris, [2] iv. 312).

Toluidine red gives to vegetable and animal fabrics a shade rather more blue than that communicated by fuchsine.

Xylidine Red.—A product has been introduced by Coupier under this name, derived from xylidine by the same processes as those by which rouge de toluène is got from Coupier's toluidine. The following formulæ are given by Coupier:—Xylidine, 100 parts; arsenic acid at 75 per cent., 140 parts; commercial hydrochloric acid, 20 parts: heat for three hours to 130° to 140° C. Or heat to 200° C. xylidine, 75 parts; and of the corresponding nitroxylidine, 105 parts. This red dyes animal and vegetable fibres a more violet shade than fuchsine and rosatoluidine. Of the composition of this red, and its relation to rosaniline and the other red dyes, nothing is known; but without doubt its composition is analogous to that of rosaniline. These results are entirely different from those of Hofmann, who found that xylidine alone, or mixed with toluidine, gave no red; but that a fine red could be formed from a mixture of aniline and xylidine by the action of arsenic acid. The red derived from aniline and xylidine is not necessarily identical with the "xylidine red" or "rosaxylidine" of Coupier.

Ulrich's Scarlet.—Four parts of rosaniline acetate are dissolved in hot water, and mixed with a solution containing 3 parts of lead nitrate; the whole is then evaporated to dryness, and heated to 150° to 200° C. until the whole mass is violet. After cooling the mass is boiled for a long time with very dilute sulphuric acid; an excess of alkali is added to the hot liquor, and the whole filtered whilst hot. The new colouring matter is contained in the filtrate, and may be precipitated by addition of salt. Perkin's mauve may also be used, and peroxide of hydrogen and other oxidizing agents can be employed with the same result; it is therefore probable that this scarlet is closely allied to Geranosine.

Geranosine.—Luthringer gives the following process for the preparation of this dyestuff:—4½ kilos. of barium or calcium nitrite or dioxide are disseminated through 25 litres of water, and 10 kilos. of strong sulphuric acid (at 66° B) are added; to this liquor is added a solution of 1 kilo. of any rosaniline salt dissolved in 1000 litres of water, and at a temperature of 45° C.; the mixture becomes citron yellow and then colourless. After filtration the temperature is gradually raised to 100° C. to separate barium sulphate, when an intense red tint is developed; after two minutes' boiling the liquor is cooled, and the dyestuff salted out and collected on filters.

This dye is not decolorized by ammonia (alkalies greatly weaken or destroy the fuchsine tint by setting free the nearly colourless basis); it is soluble either in water or alcohol.

Saffranine.—Mène gives the following process:—Aniline nitrite is prepared by passing into aniline the vapours evolved from a mixture of starch and nitric acid. The product is washed two or three times with water, and then heated with half its weight of arsenic acid to 80° to 120° C. for five minutes; the product is poured into boiling water, and lime added until the acid is neutralized. The liquor is then filtered through flannel, and the colouring matter salted out from the clear red liquor by means of common salt (5 parts to 1 of aniline nitrite). The pasty mass is then drained, and pressed to remove the brine. In preparing the aniline nitrite care must be taken that the temperature does not rise too high, otherwise the aniline will be carbonized; the delivery pipe should dip pretty deeply into the oil, and the containing vessel should be frequently agitated and cooled by water. An excess of nitrous acid must also be avoided. Besides arsenic acid, other oxidizing agents may be employed, viz.: chromic acid, a mixture of sulphuric acid and potassium dichromate, stannic chloride, &c. Of these potassium dichromate seems to be the most suitable. Simultaneously with saffranine, a violet colouring matter is formed; this is precipitated by the alkaline solution added, and is then separated.

Manufacture of Bleu de Lyons or Aniline Blue.—The preparation of good aniline blue from fuchsine and aniline oils, by simply heating the ingredients together, is an operation of some delicacy, the result depending to a great extent upon circumstances which at first sight would hardly seem to be important. The original process patented by Girard and De Laire was as follows:—Purified fuchsine is mixed with its own weight of aniline oil, and the mixture heated to a temperature as near 165° C. as possible (between 155° and 185°) for five or six hours· a violet product is obtained, 1 part of which is boiled with 10 to 12 parts of hydrochloric acid diluted with the same quantity of water; unaltered fuchsine and aniline are dissolved out, and a violet dyestuff is left. By further boiling this product with hydrochloric acid (10 of acid to 100 of water) several times successively, a pure blue colouring matter is left, which is dissolved in acetic acid, alcohol, or wood spirit, and the solution used for dying.

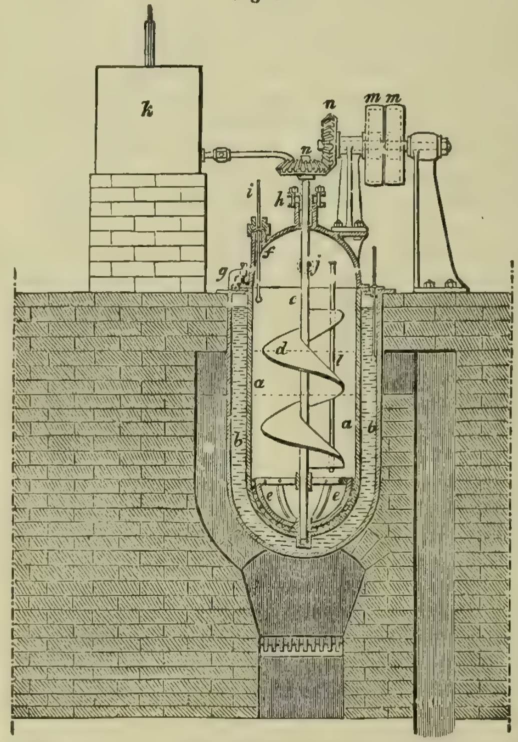
According to Reimann, it is possible to get every shade of violet in this way, but no true blue, unless the rosaniline salt of an organic acid be used, or what amounts to the same thing, unless an organic sodium or other metallic salt be added to the mass; moreover, a much larger proportion of aniline is desirable.

Levinstein's process is worked as follows:—Three parts of aniline and one of magenta are heated to 180° C. for three hours, when the red becomes violet; half a part of potassium acetate is then added, and the temperature raised to 190° C. for one hour and a half, or until a sample taken out appears of a greenish blue hue against a white background; the mass is then treated with hydrochloric acid as before. The blue thus obtained has a faint greenish tinge.

Passavant's method was to heat 4 parts magenta, 8 of aniline, and 2 of sodium acetate to 200° C. for two hours, the temperature being then raised to 250° C. When the required shade is attained the semi-fluid mass is poured into a mixture of 4 parts alcohol and 12 hydrochloric acid; the brownish cooled mass is then powdered and boiled for fifteen minutes with dilute sulphuric acid, and filtered. The residue is boiled twice successively with hydrochloric acid to eliminate the last traces of red tinge.

Bardy describes the following manufacturing process:—Rosaniline hydrochloride, 100 parts, sodium acetate, 30 parts, crystallized potassium acetate, 10 parts. The first two ingredients are mixed and evaporated to dryness; the potassium acetate and some free aniline are then added, and the whole heated to 175° C. till a pure blue tint is developed. The product is then treated with one and a half times its weight of strong hydrochloric acid; this leaves the blue undissolved. The insoluble substance is collected, washed with water, and treated with five times its weight of caustic soda ley at 32° C. After twenty minutes boiling 15 parts of boiling water are added and the whole filtered. The free base thus produced is washed with lukewarm alcohol to remove mono- and di-phenyl rosaniline, and then treated with sulphuric acid.

Fig. 6.



The hydrochloric acid solution yields a precipitate of diphenyl rosaniline in dilution with water equal to 1½ parts per 1 part of crude blue; on further adding 23 parts of water, monophenyl rosaniline is thrown down. The mother liquors are saturated with lime and mixed with acetate and chloride of sodium to recover rosaniline hydrochloride.

The process as carried out at the present day is thus described by Girard and De Laire:—An enamelled retort holding about 20 litres is heated in a paraffin bath, a cohobator and distilling worm are attached to the top (which is movable), and an agitator is provided.

Fig. 6 shows the apparatus in section through the axis; *a*, enamelled cast-iron retort; *b*, paraffin bath; *c*, *d*, *e*, agitator; the top part (*d*) helical, the lowest portion (*e*) provided with curved arms furnished with projections almost touching the bottom of the retort to prevent adhesion of materials; *f*, movable top: *g*, flange and screw nuts; *h*, packing box of agitator axle; *i*, thermometer; *j*, orifice with which the cohobator and condenser are connected, either being shut off at will by suitable taps; *k*, cohobation worm (the distilling worm is below on the opposite side of the retort); *l*, tube for blowing steam through (a hollow agitator axle may also be used); *m*, *n*, pulley and cog-wheels.

Five kilos. of acetate of rosaniline and 15 of aniline are introduced into the retort, which is then heated to 170° C. for about two hours. Samples are taken from time to time by introducing acid through a tubulation provided for the purpose. A drop is placed on a white porcelain dish, and a drop of alcohol and acetic acid added. When the operation is complete a pure blue colour should result; if a strongly marked red margin is perceptible, the action has not gone on long enough; if the aureole is not of a bright rose, but is brown or grey, the operation has been carried on too long. By practice the workman is able to hit the exact point when the product is not quite liquid, but is perfectly homogeneous, the blue being wholly dissolved in the excess of aniline. This excess (three and one-fourth times the theoretical amount) is desirable, as it enables a constant temperature to be kept up by rendering the whole tolerably fluid, and thus greatly promotes the action and improves the products. A number of these retorts may be conveniently connected with one condensing worm and worked together.

Direct Blue.—To prepare this dye all that is requisite is to free the mass from aniline. This is readily accomplished by blowing steam through, or the colour may be dissolved out by acids.

Purified Blue.—The crude product is diluted with alcohol (methylated spirit or wood spirit), and run in a thin stream into water acidulated with hydrochloric, acetic, or sulphuric acid. The blue is precipitated as a fine powder, most of the brownish impurities and bye products being retained in solution by the slightly alcoholic solution of aniline salts thus produced. The blue precipitate is then washed with boiling slightly acidulated water, and is fit for the market.

Night Blues (Bleus lumières) are prepared by washing the purified blues with warm alcohol, and dissolving in boiling alcohol. To the filtered liquid is added alcoholic ammonia or soda, when triphenyl rosaniline is precipitated in a state of considerable purity. The precipitate is then washed with boiling water and dissolved in the particular acid the salt of which is required. Bleus lumières are also sometimes prepared by boiling purified blue with a mixture of alcohol and hydrochloric acid, and allowing the whole to cool. Triphenyl rosaniline hydrochloride is less readily taken up than the impurities, and is more easily deposited. The undissolved substance is treated thus several times successively, and is then obtained pure enough for sale. Both of these processes require the use of much alcohol, and in the latter a considerable loss is occasioned through the formation of ethyl chloride. Aniline oils are therefore often used instead of alcohol as solvents. The mother liquors from these purifications are preserved and distilled with lime; alcohol first passes, then aniline and water. Unaltered fuchsine and yellow, brown, violet, &c., bye products are left in the still (together with benzoate of lime, if benzoic acid were used in the preparation of the aniline blue).

Slight modifications are made in these processes for special qualities of dyestuffs, indicated in commerce by the marks B, B B, B B B, and B B B B respectively.

Blue B.—To make a dye of this quality 2 kilos. of pure rosaniline, 3 of aniline boiling at 182° to 185° C. and free from hydrocarbons, and 270 grammes of glacial acetic acid, or of benzoic acid, are heated together for two hours, the temperature not rising above 180° C. Benzoic acid gives slightly greener shades than acetic acid, and the dyes are suitable for silk, whilst wools require dyes made with acetic acid. The aniline oil is used as pure as possible, the tritoluyl rosaniline being formed with greater difficulty, and requiring more numerous treatments to prepare purified blue than triphenyl rosaniline. The aniline that distils over during the preparation of fuchsine answers well. When the shade given by a sample treated with alcohol and acetic acid is a pure blue, with no trace of violet or grey, the contents of the retort are run into a vat (of wood or enamelled cast-iron) containing 10 kilos. of strong hydrochloric acid, with continual agitation; the mass is filtered and pressed, and well boiled up by steam with water acidulated with hydrochloric acid, until the blue is reduced to a fine powder. This is then filtered and pressed: 3500 grammes of dry blue are thus obtained. If the acetate or sulphate is required, the corresponding acid must be used in lieu of hydrochloric.

Blue B B.—The proportions for this shade are different, viz.: pure rosaniline, 2 kilos.; pure aniline, 5 litres; and glacial acetic acid, or benzoic acid, 270 grammes. The whole is treated as for the quality B. The blue is heated in a cohobator, with alcohol and benzol (1 part of blue purified up to the stage of blue B, $1\frac{1}{4}$ part concentrated alcohol, and 5 parts highly rectified benzol). After boiling one hour the whole is filtered (through closed-in filters), pressed, and dried; the alcohol and benzol are distilled off from the mother liquors and used again, an inferior blue being left behind. A mixture of alcohol and aniline is sometimes used, in which case the blue is washed finally with an acid to remove adhering aniline.

Instead of the above process, the contents of the retort may be emptied into an enamelled iron pot surrounded with water, so as to cool them quickly, and 6 to 8 kilos. of strong alcohol added, with agitation. The homogeneous mass is then heated until the alcohol just begins to boil, cooled, and precipitated by the addition of from 6 to 12 kilos. of strong hydrochloric acid added, with continual stirring; heat is evolved from the formation of aniline hydrochloride. To obtain a uniform product the precipitate should be filtered off at a temperature of 45° C., pressed, thoroughly washed with a large bulk of water, and dried; 1320 grammes of blue B B should be obtained.

Blues B B B and B B B B.—1 kilo. of dry pulverized blue B B is boiled with 26 kilos. of alcohol in a cohobator provided with an agitator; 2 kilos. of 20 per cent. alcoholic caustic soda solution are then added. The whole is well mixed and then filtered through a closed-in filter, the presence of the hot alcohol greatly assisting the operation (the cohobator tap being turned off): 280 grammes of strong hydrochloric acid are then mixed with the alcoholic liquor while yet warm, and the whole is allowed to stand two days. The crystalline precipitate is then drained and pressed—this is blue B B B; by repeating the treatment blue B B B B is obtained. One kilo. of blue B B gives 680 to 690 grammes of pure dry blue B B B; an inferior blue is obtained from the matter left in the filter, and the alcoholic mother liquors, by dilution with water. The aqueous acid alcohol is rectified over lime and recovered.

Instead of pure alcohol a mixture of alcohol and aniline may be used with advantage: 1 kilo. of pure dry blue B B, 1 of alcohol, and 2 of aniline, are well mixed while heating on the water bath; the viscid homogeneous mass is then poured into 25 kilos. of alcohol, and heated to boiling; the alcoholic soda is then added, and the liquor filtered and precipitated with a slight excess of hydrochloric acid. After 48 hours the precipitate is filtered off, washed with boiling water slightly acidulated, and dried; about 800 grammes of blue B B B are thus obtained, and a proportionally less quantity of inferior blue.

According to REIMANN it is impossible to get a pure full-blue from any simple mixture of aniline and magenta (rosaniline hydrochloride?). By heating together 100 parts of magenta, 100 of aniline oil, and 25 of sodium acetate, at 170° to 180° C. in an oil bath, a red violet is easily formed, and by further heating, violets and blue violets. To prepare these latter, and to transform them into a full blue or greenish blue, benzoic acid, benzoate of potassium or sodium, formate of sodium, stearic acid, stearate of sodium (common tallow soap), or some similar substance must be added. Thus, to get a blue violet 1 part of aniline, 3 of magenta, $\frac{3}{4}$ of sodium acetate, and $\frac{2}{3}$ part of soap are used, the same substances being used for blue with $\frac{3}{4}$ part of soap; the soap being added in small quantities when the other materials have acquired a reddish blue tint, and well incorporated. This product must be quickly removed when the proper shade is acquired, otherwise it becomes overheated and damaged. The mass is then treated with dilute hydrochloric acid to remove aniline and fuchsine, and well washed with water, the stearic acid set free by the action of the acid on the soap being subsequently dissolved out by benzol: 100 parts of magenta give 150 of blue when the operation is successful.

The discrepancy between **Reimann**'s statements and those of **Girard** and **De Laire** probably arises from the use of larger quantities of aniline by the latter, and the choice of aniline oils almost wholly free from higher homologues. Toluidine acts on fuchsine somewhat less readily than does pure aniline, and the resulting "toluidine blue" differs in some respects, notably in solubility and shade of colour; it is also much less easily purified, and hence is but rarely made. A patent for the production of this body was taken out by **Collin** in 1862, the process specified being the heating of equal weights of a rosaniline salt and of crystallized toluidine (paratoluidine) to between 150° and 180° for five or six hours. The unaltered toluidine and rosaniline are dissolved out from the crude mass by boiling with eight to ten times its weight of dilute hydrochloric acid. **Clark** patented a precisely similar process in 1864.

Coupier has prepared a blue from rosatoluidine by the action of aniline. A similar blue is also obtained by the action of toluidine (mixture of para- and meta-toluidine) on rosatoluidine, and according to him it possesses great beauty, and is specially easy to purify.

Manufacture of Soluble Blue (Nicholson's Blue, Alkali Blue).—The soluble blue manufactured at the present day differs slightly in composition from that prepared some years ago, being essentially the sodium salt of the mono-sulphonic acid of triphenyl rosaniline $C_{20}H_{15}(C_6H_5)_3(SO_3Na)N_3$ or $C_{20}H_{16}(C_6H_5)_2(C_6H_4SO_3Na)N_3$, whereas the older dyes were the salts (ammonium, sodium, &c.) of the corresponding di- and tri- sulphonic acids. The mono-product is somewhat less soluble in water than the others, but it yields much more stable shades.

The higher sulpho-derivatives were prepared thus:—Triphenyl rosaniline sulphate was heated by steam in a jacketed vessel to 130° to 140° C., with from 4 to 10 times its weight of strong sulphuric acid; the mass was then cooled and poured by small quantities into 8 to 10 times its weight of water, the precipitate being then collected on a filter, drained, and pressed (or dried in a centrifugal machine). It was then warmed with a slight excess of ammonia in an enamelled pan: the coloured salt rising to the surface as a golden mass, when it was skimmed off, dried, and powdered. In his original patent (June, 1862), **Nicholson** employed 10 parts of acid to 1 of blue, and heated for about an hour and a half to 150° C.; but it was soon found that a rather lower temperature and a smaller proportion of acid gave better results. A purified product, known as *Soluble Night Blue* (bleu lumière soluble), is obtained from this substance by solution in alcohol, when ammonium sulphate and other impurities are left undissolved.

The process now employed is virtually the same, with the difference that less acid is used (twice to three times the weight) and the temperature is lower, not exceeding 100° C. at the most. Thus a kilo. of purified blue B B, in fine powder, may be added to 3 litres of strong sulphuric acid on the water bath in small portions at a time, until a drop thrown into water gives a blue precipitate which does not colour water when washed by decantation several times, but is nevertheless wholly soluble in caustic soda or ammonia. The whole is then poured with continual stirring into wooden vats containing 30 litres of water; after twenty-four hours the precipitate is collected, drained, and heated on the water bath or by steam, with the exact quantity of caustic soda required. The product is dried on enamelled iron plates in a hot chamber, pulverized, and mixed with 20 per cent. of its weight of soda crystals.

Or two parts of acid and one of blue B B are treated at as low a temperature as possible until rendered just soluble; the product being precipitated by water, washed, pressed, and dried.

Vogel proposed to heat triphenyl rosaniline with 8 parts of fuming sulphuric acid to 130° for six hours; higher substitution acids than the mono-sulphuric acid are thus produced.

Leonhardt prepares a very finely divided blue, by dissolving the soluble blue in alcohol, and then precipitating with water.

The alkaline salts of soluble blue are almost colourless; to develop and fix the colours an organic acid (such as acetic) is preferable to a mineral one.

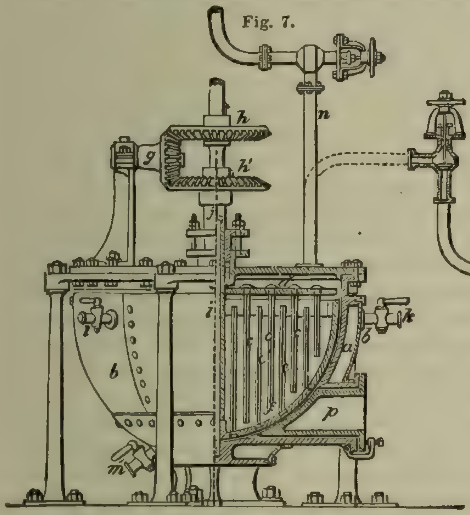
Manufacture of Diphenylamine Blue.—Although any fuchsine-making material will transform commercial diphenylamine (true diphenylamine mixed with higher homologues) into blue, yet the so-called carbon sesquichloride (C_2Cl_6) gives the best results, both as respects yield and quickness of working. **Brinmeyr** has, however, obtained the same product by simply heating diphenylamine and oxalic acid to 110° to 120° C. for some hours.

Girard and **De Laire** thus describe their process; the operation is effected in enamelled iron retorts provided with agitators, and heated in an oil bath, their capacity being about 50 litres:—12 kilos. of sesquichloride of carbon, and 10 of commercial diphenylamine, are introduced and gently heated; at 160° C. the reaction commences, and at 180° C. it goes on steadily; a higher temperature risks the formation of a violet product in lieu of a blue one. So-called protochloride of carbon (C_2Cl_4) distils over throughout the operation, and is collected in a graduated vessel; a quantity almost exactly corresponding to the amount of sesquichloride used should be obtained. A sample is drawn from the retort with a rod from time to time; when this (after cooling) is of a copper red colour, does not soil the fingers, is dry and friable, and dissolves in alcohol to an intensely blue liquor, the calculated quantity of protochloride of carbon having been likewise obtained, the operation is finished. This usually takes from three to four hours. The mass is then poured out upon iron cooling plates, and purified by one or other of the following processes:—

No. 1. One part of crude blue is dissolved in two of aniline, at a temperature not above 100° C., and the solution poured in small quantities, with continual stirring, into 10 parts of benzol; a closed vessel should be used to avoid loss by evaporation, two hours at least being required for this operation. The precipitated blue is collected on calico filters, drained, pressed, and treated in the same way over again; the drained (but not pressed) precipitate thus obtained is washed with 5 parts of benzol, with agitation for two hours, The powder is then collected on a filter, dissolved by heat in 2 parts of aniline, and precipitated by 4 parts of ordinary hydrochloric or acetic acid. The precipitate is washed with a little boiling water (the runnings being saved to regain the aniline hydrochloride) and then with a large bulk of hot water: care must be taken not to use calcareous water.

No. 2. The crude blue is boiled with an alkaline lye in an apparatus such as that denoted in Fig. 7, in which *a* is a hemispherical vat, surrounded by a steam jacket, *b*; *c*, *c*, are the vanes of the upper agitator, *d*; and *e*, *e*, the vanes of the lower agitator, *f*; *d* and *f* are two agitators having their respective motions in opposite directions, and working after the fashion of a Carr's disintegrator; *g*, *h*, and *h′*, the cogwheels for giving these motions; *i* is the *solid* axle of lower agitator; and *j*, the *hollow* axle of the upper agitator; *k*, *l*, taps at the entrance and exit steam-pipes; *m*, a tap admitting steam into the interior; *n*, the connection with cohobator; *o*, the connection with distilling worm (neither of these connections are necessary for aqueous solutions); *p*, the discharging orifice. The base set free is pressed, dried, pulverized, and exhausted with petroleum hydrocarbons boiling at 70° to 100° C. in closed vessels. The residue is then boiled with water (to expel the hydrocarbons) dried, pulverized, and then dissolved in warm alcohol, filtered, and precipitated by 10 per cent. of strong hydrochloric acid; some impure hydrochloride of rosaniline is thus thrown down. The liquor containing the colouring matter is exactly neutralized with soda and subjected to distillation to obtain a crystalline blue, which is then washed with boiling water to get rid of alkaline salts.

Fig. 7.



No. 3. The crude blue is dissolved at a temperature not higher than 60° C. in 10 parts of strong sulphuric acid. When complete solution is effected, 30 parts of water are added; the blue is precipitated, whilst a violet bye product remains for the most part in solution. The liquor is filtered through asbestos or glass powder, and washed, first with dilute acid, such as the mother liquors themselves, and finally with pure water, till no longer acid: the mass is then pressed, dried, and purified either by benzol, or petroleum and alcohol, as in processes Nos. 1 and 2.

The violet residues from these processes are collected and subjected to distillation, to regain diphenylamine.

No. 4. The petroleum treatment is adopted, as in No. 2, the blue is then dissolved in acetic acid, and the resulting acetate in a mixture of 4 parts aniline and 10 of alcohol; the liquor is filtered in covered vessels, and the base set free by alcoholic soda. Finally, the liquor is filtered and precipitated by hydrochloric acid. A chemically pure product is thus obtained.

The acid-alcoholic aniline solutions are diluted with water, and then rectified over lime.

Preparation of Mulhouse Blue.—GROS RENAUD and SCHŒFFER boil together:—White gum lac, 50 grms.; sodium carbonate, 18 grms.; solution of azaleine (rosaniline nitrate), 50 grms.; water, 1 litre, for one hour, water being added from time to time to supply loss by evaporation. The azaleine solution referred to is prepared by dissolving 125 grms. solid azaleine in 1 litre of a mixture of equal volumes of water and alcohol. The resulting liquor possesses the same tint as that of an ammoniacal solution of a copper salt. A violet product (*Violet de Mulhouse*) may be obtained by using more of the azaleine solution; this is probably only a mixture of the blue with unaltered azaleine.

Preparation of Aldehyde Blue.—This is prepared in the way described under aldehyde green. Many attempts have been made to utilize this dye, especially for worsted, &c.; but its want of permanence is too great.

Preparation of Azuline.—MARNAS prepares this blue colour by heating to the boiling point a mixture of 5 parts of coralline (*pêonine*, the product of the action of ammonia on rosolic acid, *vide* article Carbolic Acid), and aniline 6 to 8 parts, until nearly all is transformed into a blue colouring matter, which is purified by successive washings, first with water acidulated with hydrochloric or sulphuric acid; secondly, with hot oils from coal tar; next, with dilute caustic alkali; and finally, with water slightly acidulated. The product is a reddish powder with a golden lustre, soluble in alcohol and methylated spirits, which solution can be used for dyeing. An analogous blue colour is producible by the action of naphthylamine on rosolic acid.

Manufacture of Azurine.—CALVERT, LOWE, and CLIFT printed cotton goods with this tint in the following way:—A liquor is prepared from chlorate of potassium, 1 part, and water, 40 parts. The goods are rinsed in this liquor, dried, and then printed with a 1 per cent. solution of aniline tartrate or hydrochloride, thickened with starch. Or, the following mixture is taken for printing on the cotton goods without any previous treatment:—1 part of aniline, 2 of tartaric acid, 60 of starch, and 1 of potassium chlorate. The potassium chlorate is dissolved in the hot starch paste, and after cooling the aniline bitartrate solution is added. In this way a *green* tint, "Emeraldine," is communicated. When the goods thus printed are immersed in a bath of 1000 parts of water and 25 of soap, or of 1000 parts of water and 6 of caustic soda, or of 1000 parts of water and 6 of potassium dichromate, this green tint becomes blue (Azurine).

Blumer-Zweifel uses the following formula for Emeraldine:—Water, 1000 parts; starch, 100; potassium chlorate, 4; sulphate of iron, 3 to 4; sal ammoniac, 10; a salt of aniline, 60. The water is boiled and the starch is made into paste with it; the chlorate of potassium, sulphate of iron, and sal ammoniac are dissolved in the hot liquor; after cooling the aniline salt is added. Another recipe is as follows:—15 parts of nitric acid, 6 to 8 of water, and 10 of aniline. To this add sufficient starch or British gum to thicken, together with 10 parts of sugar, and 4 to 8 of potassium or sodium chlorate. The Emeraldine is developed by exposing the goods to the air for from twenty-four to thirty-six hours after printing, and the blue tint is then given by one of the above baths for that purpose.

Manufacture of Mauve.—The following description of this manufacture is given by Perkin (*Chem. Soc. Journal*, 1861):—Solutions of equivalent proportions of aniline sulphate and potassium dichromate are mixed and allowed to stand; the whole is then filtered and washed with water until free from potassium sulphate. The precipitate is dried and digested several times successively with coal tar naphtha, until all resinous matter is separated, and the naphtha is no longer coloured brown. After this it is repeatedly boiled with alcohol to extract the colouring matter. The alcoholic solution when distilled, leaves the dyestuff at the bottom of the retort as a beautiful bronze-coloured substance.

The product as thus prepared, though suitable for practical purposes, is not chemically pure: if required pure, it is best to boil it in a large quantity of water, to filter off the coloured solution thus obtained, and to precipitate the colouring matter by addition of an alkali. The precipitate should then be washed with water till free from alkali, and then dried. The residue is dissolved in absolute alcohol, and the solution evaporated on the water bath.

Scheurer Kestner describes the following industrial process:—Mix commercial aniline, 1 kilo.; cold saturated aqueous solution of potassium dichromate, 800 to 1200 grains; sulphuric acid at 66° B, 500 grammes. Wash the precipitate first with cold and then with boiling water, to which 1 to 2 per cent. of acetic acid is added; evaporate the acid filtrate, filter, and add caustic soda till no more precipitate is thrown down; collect the precipitate and wash with a dilute alkaline liquor, whereby a red colouring matter is removed; then wash with water till this filtrate is colourless; drain the resulting paste thoroughly. The dyestuff may be sold thus, or the paste may be purified by solution in boiling water and precipitation by alkali, or by solution in alcohol and evaporation to dryness.

Schlumberger describes the following process as worked by Geigy & Co., of Basle:—Mix in a vat holding 400 litres, and heated by a steam tube, 60 litres of water, 4 kilos. of aniline, and 2·12 kilos. of sulphuric acid at 66° B. This mixture is boiled, and then allowed to cool. When cold they add in a thin stream, and with continual stirring, a cold solution of 6·36 kilos. of potassium dichromate and 40 litres of water. The mixture is agitated at intervals for two days, and hot water is then added till the vat is full. After settling, the precipitate is washed by decantation and filtration, with diluted sulphuric acid at 2° B; lastly, the filtrate is washed with water, till it is no longer yellow.

From this product the colouring matter is dissolved out by boiling by steam for two hours in wooden vats holding about 400 litres. The filtered liquors are precipitated with caustic soda and common salt; the precipitate is collected, slightly washed to remove excess of alkali; and the drained paste is then treated with 5 per cent. of acetic acid, boiled with water, and the filtered liquid again precipitated with soda. This process is laborious and costly, four days being required for the aqueous extraction. Instead of water, spirit of wine may be used. The crude washed precipitate is dried on metal plates, and then boiled with alcohol in a copper extracting vessel, consisting of two boilers, each heated by steam. The upper one has a perforated false bottom, on which is a calico filter cloth, above this is a fine sieve, and above this again, straw. The powder to be extracted is laid on the straw; alcohol is poured on it, and the whole heated by the steam-worm which lies under the false bottom; the vapours are condensed by a worm tube, and flow back on to the crude colouring matter. The lower boiler is so arranged as to receive the alcoholic solution which percolates through the filtering bed in the upper vessel; it is provided with a steam jacket, so that the alcohol can be distilled off. The condensed alcohol is made to drop back over the matter to be exhausted, and thus the alcohol is used over and over again until no more colour is dissolved out. On distilling off the whole of the alcohol, a pasty mass of colour is left; this is dissolved in boiling water, filtered, and precipitated with soda. According to Schlumberger, less dyestuff is obtainable by this process in summer than in winter, owing to the greater difficulty in cooling the liquors on mixing the aniline and chromic solutions. It is not desirable to use an aniline oil of higher specific gravity than 1·007.

The following industrial process is described by Girard and De Laire:—100 kilos. of heavy aniline oils are mixed with 54 of sulphuric acid at 66° B., and 2 of water, the diluted sulphuric acid being added little by little, with continual stirring. When the whole is added, the mass is heated and stirred so as to obtain a homogeneous product, and then cooled: 140 kilos. of potassium dichromate dissolved in as little water as possible is then added to the cold liquid, and the whole allowed to stand twenty-four hours. At the end of this time a black precipitate is formed. The vats in which this operation is conducted are then filled up with water, so as to wash the precipitate by decantation; the washing is repeated three or four times, and the precipitate collected in filters and washed with water, acidulated with sulphuric acid, and finally with pure water; the residue is then boiled with water for three hours with continual agitation. A violet solution is thus obtained, which is filtered and precipitated with an alkali; the precipitate is washed with lukewarm water and dissolved in acetic acid. To obtain a pure product the process should be repeated several times. From 68 to 90 kilos. of thick mauve-paste may thus be obtained from 100 of heavy aniline oil (Girard and De Laire); an average of 70 parts of paste, containing 10 per cent. of dry colouring matter (Schlumberger).

Tabourin and Franc use hydrochloride of aniline in lieu of sulphate in the preparation of Perkin's mauve.

Glavel prepares a soluble mauve by treating the colouring matter with fuming sulphuric acid, with continual agitation: after standing for half an hour the whole is greatly diluted with warm water and boiled. After cooling, common salt is added to precipitate the colouring matter, which is then collected and washed with water till the acid and salt are removed. It is wholly soluble in warm water, and the aqueous solution can be used direct for dyeing.

Dale and Caro's process is worked as follows:—One equivalent of aniline hydrochloride, sulphate, acetate, or nitrate, and 6 of chloride of copper, are dissolved in water (30 times the weight of the aniline salt), and boiled till nothing more precipitates. This requires three to four hours. The black precipitate is then washed on a filter with a weak solution of soda until all chlorine is removed, and boiled with water as above. The filtered liquid is precipitated with a little soda, and the precipitate washed, when it is fit for use. Some dyestuff is left in the residue insoluble in water, whence it can be extracted by alcohol. A mixture of sulphate of copper and chloride of sodium, in equivalent quantities, answers as well as copper chloride.

Bleaching Powder Process.—This process, originally proposed by Bolley, and subsequently patented with slight variations by Beale and Kirkham, may be worked as follows:—One part of aniline is dissolved in 1 of hydrochloric acid and 3 of water, and then added to 60 parts of a solution of bleaching powder of such a strength as to contain 1½ per cent. of its bulk of free chlorine gas; a black precipitate is thrown down, which is well washed, and dissolved in a little sulphuric acid. On addition to the latter solution of a large bulk of water, a precipitate is thrown down which is washed and purified as in Perkin's process. The product has frequently a redder tinge than the mauveine made by the bichromate process; but the yield is usually somewhat greater.

Ethyl Mauveine.—The hydriodide of ethyl mauveine has been sold as a dyestuff. Equal weights of mauveine and ethyl iodide are heated together to the boiling point for four to five hours; the excess of iodide is then distilled off, and the residue dissolved in 16 to 20 parts of boiling alcohol; after standing twenty-four hours, the liquor is filtered. It is noteworthy that this substance has a *redder* shade than mauveine, whilst ethylated rosanilines are *bluer* than rosaniline itself.

Manufacture of Violets de Lyons. — (Mono- and diphenyl- rosaniline). These violets are now almost wholly superseded by the Hofmann and methyl violets. They were prepared some years ago by essentially the same process as that used for aniline blue, except that a smaller proportion of aniline was used and the operation was shortened. According to E. Kopp many of the violets in the market about 1865 were simply mixtures of substances containing unaltered fuchsine and aniline blue: such mixtures do not answer well for dyeing purposes (*Bull. Soc. Chim.* Paris, [2] iii. 153). Girard and De Laire's process was as follows: — Equal weights of purified aniline oil and of a rosaniline salt (arseniate, hydrochloride, oxalate, or acetate) were heated in a cohobator placed in an oil or paraffin bath for several hours to a temperature between 155° and 180° C. The violaceous mass thus produced was digested with warm dilute hydrochloric acid, which dissolved out the unaltered aniline and fuchsine, leaving behind a violet mass soluble in alcohol, wood spirit, strong acetic acid, or boiling dilute acetic acid. Any of these solutions can be used for dyeing.

According to the duration of the operation a red or a blue violet could be produced; these were sold as "Imperial red violet" and "Imperial blue violet" respectively. In permanency they are inferior to Perkin's mauve, but superior to the Hofmann violet.

Girard and De Laire have since described the following process for preparing these two dyes (*Traité des Derivés de la Houille*, Paris, 1873):—

*Red Violet or Dahlia.**—Fourteen kilos. of aniline free from moisture, and 10 of anhydrous sulphate or hydrochloride of rosaniline, are heated gently in the cohobator; for the first half hour the aniline is allowed to drop back, but afterwards the cohobator is shut off. The temperature is then raised, but is not allowed to pass 190° C.; samples are drawn every five minutes by means of a rod; when a tint is attained rather redder than that ultimately desired (as the purification operations remove unaltered rosaniline), the heat is withdrawn and the mass cooled. This takes from one and a quarter to one and a half hour's cohobation. While still fluid it is gently poured into excess of benzol with continual agitation. Unaltered aniline and brown and chestnut products remain dissolved, whilst rosaniline and the violet precipitate. The precipitate is pressed, dried, and dissolved in strong hydrochloric acid; water is then added, when the violet is precipitated and washed with pure water and dried, whilst the rosaniline remains in solution. The benzol containing aniline is treated with hydrochloric acid to throw down aniline hydrochloride and colouring matters, and is then distilled over an alkali.

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* This term has been applied to many kinds of dyestuff having approximately the same tint; notably to ethylated mauveine and to a product manufactured by a process kept secret, but stated to be obtained from residues in the fuchsine manufacture.

Instead of running the mass into benzol, it may be slightly diluted with alcohol and run slowly into acidulated brine; an impalpable powder then precipitates, which is well washed with fresh acidulated brine, and finally with pure water, after which it is pressed and dried at a temperature not above 40° C.

Blue Violet.—The operation is conducted just as for violet, using, however, a little more aniline (twice the weight of rosaniline salt, *i.e.*, 20 kilos. aniline and 10 rosaniline salt), and allowing a somewhat longer time, viz., from twenty to thirty minutes, so that the operation lasts one and a half to two hours. Too high a temperature must be carefully guarded against during the last quarter of an hour, and the sample must be drawn at very short intervals. When finished the mass is slightly cooled, and 4 to 5 litres of alcohol gently run in with continual stirring. The whole is then poured into 400 litres of alcohol acidulated with hydrochloric acid; after which brine is added to throw down the colour. Rosaniline and some violet red remain dissolved. The precipitate is washed first with dilute acid, and finally with pure water, till no longer acid. If the heating operations have been pushed too far the product is slightly resinous, and should be washed with weak alcohol; as also if the shade is a little too red. If much insoluble matter is present, the whole should be dissolved in strong alcohol in an agitating apparatus.

Manufacture of Hofmann's Violets. — The three varieties, marked R, B, and B B, of these violets, are prepared in much the same way, the chief difference in the processes being the proportion of the alcoholic iodide used. In the early days of the manufacture the process was conducted under the ordinary atmospheric pressure, in a digester provided with a cohobater and condensing worm and an agitator, and surrounded by a steam jacket. At the present day autoclaves are usually employed, and the action is brought about under a greatly increased pressure. After about two hours' heating at about 115° to 130° C., the operation is finished. The alcohol and excess of iodide is distilled off, and the residue is ready for the market if the hydrodides of the resulting bases are required.

Instead of heating by steam a saline bath may be used. Thus, a solution of calcium chloride may be used, or even brine. If the temperature be lower than the above, a longer time is requisite; thus, four or six hours, or even more, at 100° to 110° C., is required. When the digester is opened permanent gases (ethylene and methylic ether?) escape; the manhole must therefore be opened cautiously, otherwise effervescence and loss of material ensue. For the three qualities the following proportions may be used (Girard and De Laire):—

	R	B	BB
Rosaniline, . . .	10 kilos.	10 kilos.	10 kilos.
Alcohol, ...	100 litres.	100 litres.	100 litres.
Methyl or ethyl iodide,	8 kilos.	5 kilos.	20 kilos.
Caustic potash or soda,	10 "	10 kilos.	10 "

According to the patent specification of Hofmann (May 22, 1863), the following proportions may be used for violet:—1 part of magenta, 2 parts of ethyl iodide, and 2 of methylic or ethylic alcohol.

Ethyl iodide does not give the bluer shades so readily as methyl iodide; hence, for the B B colour methyl iodide only is usually employed. If, however, methylic alcohol be employed together with methyl iodide, methyl iodide and ethylic alcohol are formed; thus—

$$CH_3.OH + C_2H_5I = C_2H_5.OH + CH_3I.$$

So that blue shades may be obtained with methyl iodide if wood spirit, or even ordinary methylated spirit, be employed along with it.

If the hydriodides of the violet bases are used in dyeing, it is necessary to employ alcohol as a solvent, the salts being insoluble in water. In addition, the high price of iodine at the present day renders it necessary to recover the iodine; *i.e.*, to convert the hydriodides into other salts. For this purpose the crude hydriodides are boiled with alcoholic caustic soda in a digester; the mass is then washed with hot water to separate sodium iodide and excess of caustic soda, and dissolved in hydrochloric, sulphuric, or acetic acid. From this filtered solution the dyestuff is thrown down by common salt, and is collected and dried. The product is perfectly soluble in cold water if pure.

Some manufacturers employ the alcoholic bromides in lieu of the iodides. The hydrobromide and ethyl bromide of triethyl rosaniline are sometimes met with in commerce.

As already stated, the violet B B consists chiefly of a salt of trimethyl rosaniline. In addition the salts of the mono- and tri- methylates of trimethyl rosaniline are usually present also to a small extent. Both of these are violet blue dyes.

Some few dyes have likewise been prepared by processes similar to those used for making Hofmann's violets. Methylated and ethylated mauvanilines are thus prepared from mauvaniline; benzyl chloride violets from rosaniline and benzyl chloride; benzyl-methyl violet from Hofmann's violet R and benzyl chloride; phenyl-methyl violet from violet de Lyons and methyl iodide; and isopropyl, amyl, allyl. and other analogous violets from isopropyl, amyl, allyl, &c., iodides, and rosaniline.

Turpentine Violet (*Britannia Violet*).—The reaction employed by Perkin in the production of this violet has been used in the preparation of other analogous products. Turpentine is dropped into bromine water, and the whole shaken together till no free bromine is left. One part of the brominated turpentine, 1 of rosaniline, and 6 of wood spirit or alcohol, are then heated in an enamelled autoclave for eight hours to 140° to 150° C. After cooling, the product is dissolved in alcohol or other like solvent. A red shade is obtained with 2 parts brominated turpentine, 3 of rosaniline, and 15 of alcohol; a blue shade, with a larger proportion of brominated turpentine.

Levinstein's Dorothea is formed by heating together at 100° C. for two to three hours a mixture of 90 per cent. alcohol, 50 parts; rosaniline, 35 parts; and nitric ether, 9 parts.

Manufacture of Methyl Violets.—The following process is described in the patent specification of Poirrier and Chappat:—Mix the methyl and dimethyl aniline obtained by their process with five to six times its weight of chloride of tin perfectly free from water, and heat to 100° C. for several hours, when the mixture becomes solid and hard. The product is then cooled and boiled with caustic soda ley. The free base remains undissolved, and can be obtained as salt by solution in any acid. Mercuric chloride can also be used. The exact point at which the heating must be stopped is known by practice. If the heating be carried on too long, much black tarry bye-products are also formed.

The following processes are also described in a later specification:—A mixture of 100 parts methyl aniline sulphate, 100 to 150 of powdered potassium chlorate, and 100 to 150 of water, is heated for several hours at 160° C. Chloride of iodine may be used in place of chloride of tin; or a mixture capable of producing chloride of iodine, such as methyl aniline, 100 parts; iodine, 20 parts; and potassium chlorate, 20 parts.

The following mixtures may also be used:—Methylaniline, 1 part; mercuric chloride, 1½ part; and potassium chlorate, 1 part; or, methyl aniline, 1 part; mercuric iodide, 3 parts; and potassium chlorate, 1 part; or, methyl aniline, 1 part, and benzene hexachloride ($C_6H_6Cl_6$), 3 to 4 parts; in this last case the heating should be effected at 150° to 160° C. Blue and green tints can be produced by further treatment of the products with methylic, ethylic, &c., iodides. (*Bull. Soc. Chim. Paris* vi. 502.)

Lauth has patented the following processes:—Methyl aniline is heated to 120° C. with half its weight of hydrochloric acid for as long a time as any colour is formed, or to 100° C. with half its weight of nitrate of copper; or 2 parts of methyl aniline acetate is heated to 100° C. with 1 part of mercury oxide. The longer the heating is continued, the bluer the shade. He also states that methyl violet is readily producible by simply heating a mixture of a methyl aniline salt and sand to 100° to 120° C. Ten parts of methyl aniline, 3 of hydrochloric acid, and 200 of sand answer well. The mass simply requires to be cooled with water, which extracts the colouring matter. Care must be taken to employ in the preparation of the methyl aniline used an aniline oil boiling almost wholly near 182° C., as oil containing more than 5 per cent. of higher homologues of aniline is not suitable for the production of good colours.

Hofmann uses a mixture of 10 parts of dimethyl aniline, one of potassium chlorate, 2 of copper sulphate, and 100 of fine sand, and heats on the water bath for several days. Water and aniline are evolved. The following mixture may likewise be used:—dimethyl aniline, 10 parts; common salt, 2 parts; copper nitrate, 1 part; water, 1 part; and fine sand, 100 parts. These are well mixed. After an hour 2 parts of glacial acetic acid are added, and after two or three hours the mass is made into cakes and dried at a temperature not exceeding 50° C. for two days. The mass is then digested with a solution of sulphide of sodium of sp. gr. 1·162, 1 part of liver of sulphur being used per 10 parts of dried cake. The residue is well washed with cold water, dissolved in a large bulk of boiling water, and the dyestuff precipitated from the liquor by common salt.

Preparation of Regina Purple (Nicholson's Purple).—Nicholson describes the following process in his patent specification, dated 1862:—Aniline red is heated to between 390° to 420° Fahr. (199° and 215° C.) in a suitable apparatus. The substance quickly assumes the appearance of a dark, semi-solid mass, the red dye being transformed into a dark substance with evolution of ammonia. The mass is extracted, preferably with acetic acid about equal in quantity to the red dye used, and the acid solutions are then diluted with sufficient alcohol to make a dye of convenient commercial strength. The violet liquor may be used directly for dyeing

Emeraldine. [*Vide* Azurine.] This term has also been applied to the following dyestuff.

Manufacture of Aldehyde Green.—One kilo. of rosaniline is dissolved in 2 of sulphuric acid of specific gravity 1·63, previously diluted with 500 grammes of water: 4 kilos. of a concentrated alcoholic solution of aldehyde are then added in small quantities at a time. In from fifteen to twenty minutes the reaction is finished and the blue colour developed; the mixture is next thrown into 85 litres of water containing in solution 4 kilos. of sodium thiosulphate (hyposulphite), and the whole boiled for seven or eight minutes and filtered. A bluish grey substance is retained, whilst a solution of the green passes through; the filtrate is then precipitated by either sodium acetate, tannin, oxide of zinc, or a zinc salt and an alkali; the precipitate is washed with water, dissolved in alcohol, and thence precipitated by an alkali.

The bluish grey insoluble substance frequently forms the larger part of this product; it is often sold under the name of *Argentine.*

Many other processes, slightly varying from the above, have been given. Thus, Bolley gives the following formula for the preparation of the aldehyde blue in the first instance: 20 parts of crystallized fuchsine are dissolved in 280 of commercial hydrochloric acid; an equal bulk of water is added, and 100 parts of crude aldehyde, and the whole allowed to stand for twenty-four hours.

Usèbe gives another recipe, viz.: rosaniline sulphate, 150 grammes; strong sulphuric acid, 3 kilos.; water, 1 kilo.; crude aldehyde, 225 grammes. Dissolve the rosaniline salt in the acid and water, gradually mix the aldehyde, and then add the liquor to a solution of 450 grammes of sodium thiosulphate in 30 litres of hot water, and boil for a few minutes. Another mixture is: rosaniline salt, 300 parts; diluted sulphuric acid (3 parts acid, 1 water), 900 parts; aldehyde, 450 parts; sodium thiosulphate, 900 parts; dissolved in 60,000 parts of water.

Lucius takes 1 part of rosaniline sulphate, 2 parts of sulphuric acid, 2 to 4 of water, and 4 of aldehyde. This mixture is allowed to stand at 50° C. until a sample dissolves in 50 times its weight of alcohol with a green-blue colour: from 300 to 500 parts of a saturated aqueous solution of sulphuretted hydrogen are then added to the whole, which is slowly heated to 90° to 100° C.: 10 parts of saturated aqueous solution of sulphurous acid are then added, and the liquor filtered to separate a blue precipitate.

Hirzel employs ammonium sulphide in lieu of thiosulphate.

Aldehyde green is usually prepared by the dyer himself as required; as the dye-stuff will not keep well, becoming dull in colour and finally useless, it is rarely manufactured for the market.

Schlumberger prepared a very similar product, *Toluidine green*, by treating Coupier's rosatoluidine by the same process as that employed in the preparation of aldehyde green from fuchsine.

Manufacture of Iodine Green.—To produce this dyestuff, Keiffer dissolves 1 part of Hofmann's violet in 3 of alcohol, adds from ½ to 1 part of ethyl iodide, and then heats in a digester or in a cohobating vessel for half an hour; aqueous caustic soda or potash is then added, and the whole boiled for three to four hours. The residue is washed (the wash-waters being retained for the recovery of the iodine), and boiled with 500 to 600 parts of water; the filtered fluid is then precipitated with picric acid.

Wanklyn and Paraf heat equal quantities of rosaniline, wood spirit, and ethyl iodide (or isopropyl iodide or other homologues of ethyl iodide) to 110° to 115° C. for from three to four hours in an autoclave or cohobator, and then boil with 4 to 5 times their weight of water containing 1 per cent. of soda. Some green is thus dissolved, whilst much Hofmann's violet remains; this is again treated with equal quantities of wood spirit and ethyl iodide, and so on as before. Most of the violet is thus transformed into green, which is dissolved by the soda ley.

To obtain a good product it is essential that water should be wholly absent from the materials in the first part of the process, that no free alkali should be present, and the temperature should not rise above 100° C., all of which conditions are violated in the method adopted for Hofmann's violet manufacture; hence but small quantities of this substance are formed as bye-products during the preparation of these dyes, although it invariably accompanies the bluer shades. Ethyl iodide does not give a good yield, nor is the product of good quality. The nature of the rosaniline salt has some influence on the reaction, the acetate being the most suitable, and after that the sulphate, nitrate, and benzoate.

The manufacture from methyl iodide is thus described by Girard and De Laire (*Traité des Derivés de la Houille*, Paris, 1873):—10 kilos. of pure rosaniline acetate, 20 of methyl iodide, and 20 of methylic alcohol boiling at 64° to 70°, are introduced into an enamelled iron autoclave, capable of bearing a pressure of from 20 to 25 atmospheres. Steam is passed through the worm in the water jacket, the pressure never being above 1 atmosphere, and hence the water not being heated beyond 100°. If the temperature rise above 100° the methyl green is decomposed into mono-methyl iodide of trimethyl rosaniline, and free iodide of methyl. As the reaction goes on, a considerable pressure is developed in the autoclave, rising quickly to 8 atmospheres, and then slowly to 10 or 11, beyond which it should not go. After between four and five hours the steam is cut off, and the whole cooled down; in twelve hours more the internal pressure is not above 4 atmospheres; a condensing worm is then attached, and the screw-cock slightly opened. Methyl iodide and acetate, and much methylic ether, with the excess of methylic alcohol, distil over; the semi-fluid product is transferred to a jacketed vessel heated by steam, and dissolved in 600 litres of water.

The green dimethyl iodide of trimethyl rosaniline thus passes into solution, whilst most of the violet derivatives are left undissolved. The liquid is filtered, 24 to 25 kilos. of common salt added, and crystallized sodium carbonate added in small quantities to the boiling liquor; the small quantity of violet products retained in solution by the acid set free during the reaction, is precipitated as the acid becomes neutralized. When a sample of the liquid filtered through sand shows a pure green tint free from all trace of blue or violet, a cold saturated solution of picric acid free from nitric acid, containing 3·46 kilos. is added. A picric acid compound of the green dye is thus thrown down, sparingly soluble in water; this is collected, slightly washed, and sold as a paste. Being so sparingly soluble, alcohol must be used as a solvent; moreover, the picric acid gives a strong yellow cast, hence it is preferable to use other precipitants. Zinc chloride, sulphate, or acetate, form more soluble double compounds, and are hence much used for this purpose. They are usually sent into the market dry.

A crystallized green is sometimes prepared by dissolving the crude product in much less boiling water than that above stated, and allowing it to cool after more completely saturating with carbonate of soda. Silky needles are then deposited on copper rods placed in the liquor, a less pure crystalline magma being found at the bottom of the vessel. These crystals are drained, slightly washed with water to remove adhering brine, and dried at the ordinary temperature.

Of late, iodine green has been sold as a chlorinated compound, prepared by setting free the dimethyl hydrate from the dimethyl iodide by an alkali, and then dissolving in hydrochloric acid.

Sixty per cent. of the total yield is obtained by the above process as green dye, and forty as a violet dye, chiefly mono-methyl iodide. This may be purified and sold as a violet, but is usually transformed into green. A finer and purer green dye is thus obtained than by the direct treatment of rosaniline. The violet mass is well washed, dried, and pulverized, dissolved in alcohol, and transformed into free base by alcoholic caustic soda. It is then heated with the equivalent amount of methyl iodide to a temperature not above the boiling point of the latter, namely, 48° C. Combination takes place quickly; and when it is completed (known by the tint of a sample drawn), the product is cooled and acetic acid added. The whole is then thrown into a large bulk of warm water. A little unaltered violet is thus precipitated. The solution is purified as before.

Methyl Green.—Poirrier and Chappat describe the following process (Patent No. 72561: *Bull. Soc. Chim. Paris*, [2] vi. 504).—Heat in a close vessel, for about twenty-four hours, to 100° C., a mixture of 1 part Paris violet, 2 parts of alcoholic iodide, 2 of methylene (methylic alcohol ?), and $\frac{1}{5}$th of sulphuric acid. The mass is next saturated with an alkali, when the green colour is precipitated; this is separated by filtration, whilst a blue is retained in solution. Bromides may be used instead of iodides. As regards this latter point, Hofmann and Girard have shown that bromide of methyl or ethyl may be readily formed by the action of methylic or ethylic alcohol on amyl bromide, amylic alcohol and methyl or ethyl bromide being produced thus—

$$C_5H_{11}Br + CH_3,OH, = C_5H_{11},OH + CH_3Br.$$

By using a mixture of methylic alcohol and amyl bromide, instead of methylic iodide, the same result is arrived at by cheaper means, the price of bromine being far less than that of iodine, and the practical inconveniences attending the greater volatility of the alcohol radical bromides being thus obviated.

"Ethyl green" from Paris violet is frequently of a much finer shade than ordinary iodine green. It is also stated that methyl green is more stable in daylight than iodine green. Whether this arises solely from greater purity, or points to the substances not being actually identical, but only isomeric, is not at present known.

Methyl chloride, or a mixture of materials that will give rise thereto, such as a mixture of methylic alcohol and sal ammoniac, may be substituted for methyl iodide. In this case the corresponding trimethyl rosaniline dimethyl chloride is formed; this gives a well-crystallized zinc salt.

Manufacture of Various Browns.—Girard and De Laire's Brown.—Four parts of anhydrous aniline hydrochloride are fused, and one of dry fuchsine or aniline red is gradually added. When completely dissolved, the temperature of the mixture is raised to the boiling point of aniline hydrochloride, namely, about 240° C. The mass is allowed to boil until the colour (which is at first a violet red) suddenly changes to chestnut. The operation lasts from one to two hours, no alteration apparently taking place at first; at the close a yellowish vapour is emitted, and at the same time a peculiar odour is perceptible, resembling that of phenyl cyanide.

The resulting chestnut is soluble in water, alcohol, and acids. It may be either used immediately (*Direct brown*), or may be dissolved in water, and the dyestuff salted out with common salt, or almost any other saline solution, or a free alkali. It gives fine shades, especially on leather and silk.

Girard and De Laire consider that this substance is probably a chrysotoluidine derivative, formed from the original fuchsine by the action of toluidine on the aniline salt used.

Wise's Brown.—A mixture of equal weights of formic acid and fuchsine is heated to 140 to 210° C. for several hours; an orange red mass results. This is allowed to cool, and then again heated with 3 parts of aniline to about 230° C. for an hour or two. The mass is purified by dissolving it in dilute hydrochloric acid, and salting out the colouring matter in the usual manner.

Another process is to employ rosaniline, 2 parts; formic acid, 2 parts; and sodium acetate, 1 part: heat as before, again treating the product with 3 parts of aniline.

Jacobson obtains an analogous brown by heating to 100° C. a strong solution of ammonia chromate, mixed with aniline formate; or by heating to 140° C. 1 part of picric acid and 2 of aniline, as long as ammoniacal vapours are evolved. The product is dissolved in hydrochloric acid, and precipitated by soda.

Sieberg's Brown.—The impure fuchsine obtained from rosaniline mother liquors (sometimes known as *Cerise*) is added to twice its weight of melted aniline hydrochloride, and the whole heated on a sand bath till the brown tint appears. The product is well stirred with 4 parts of soda crystals dissolved in 25 times as much water, and the undissolved portion well washed with water. When used, 1 part of dry colour is dissolved in 9 of alcohol, 13 of water being then added.

Probably all these browns are more or less impure chrysotoluidine, or its substitution derivatives. Knap brought into the market in 1869 two dyestuffs of this description, one chestnut, under the name of *Marron;* the other approaching to orange-yellow, termed *Vesuvine. Cannelle Brown*, *Manchester Brown*, *Bismarck Brown*, and numerous other names, have been given by various manufacturers to similar products.

Leucaniline Browns.—Durand prepares leucaniline from fuchsine by boiling with zinc dust; the insoluble mass thus formed is boiled with alcohol, and the alcoholic extract evaporated to dryness, when a resinous yellow mass is left. Köchlin mixes this with sulphide of copper, and prints on cotton in just the same way as in the preparation of aniline black. Fayolle employs the mother liquor of fuchsine, and prepares an impure leucaniline salt by treatment with zinc and sulphuric acid. Caustic soda, or common salt, precipitates from the resulting liquor a mixture of products which dye yellow, nankeen, leather colour, and brown shades; the tints are darkened by passing the goods through a bath of potassium dichromate after dyeing.

Preparation of Aniline Grey.—Casthelaz prepares this dye by dissolving 10 kilos. of mauveine in 11 of strong sulphuric acid (at 66° B.); and when complete solution has been effected, adding 6 kilos. of aldehyde.

The whole is left for four to five hours, and is then poured into water, in which the grey colouring matter dissolves. The dyestuff is then salted out, and the precipitate purified by solution in water, and salting out several times successively. This dyestuff yields good tints, but is costly. Its composition is unknown. It is stated to require no mordant even with vegetable fibres. Faint shades of pearl grey may be communicated to silk and wool by means of very weak solutions of aniline violets; the finer the violet, the purer the grey.

Block prepares a grey by heating together 1 quart of aniline and 5 of fluid arsenic acid until foaming begins. The crude product is treated with a boiling mixture of 20 parts water and 5 hydrochloric acid. The undissolved portion is washed first with water, and next with dilute soda liquor, and then dissolved in alcohol containing 10 per cent. of sulphuric acid. Wool and silk are dyed with a very minute quantity of the product. (*Jahresbericht*, 1869, 1165.)

Carvès and Thirault mix a solution of 1 part of aniline in 2 of hydrochloric acid, with a mixture of ½ part bichromate of potassium, and ½ part of ferrous sulphate, dissolved in 1 part sulphuric acid and 3 of water. A viscid mass separates; this is washed with cold water and dissolved in boiling water. The solution dyes greys which withstand soap and acids. (*Jahresbericht*, 1867, 964.)

ANTIMONY.—*Antimoine*, *antimonium*, French; *antimon*, *spiessglanzmetall*, *spiessglassmetall*, German; *stibium*, Latin. Symbol, Sb.; atomic weight, Rose, 120·7; Dexter, 122·3; Schneider, 120·3.—The stibium of the Romans was the sulphide of this metal. It was used for painting the eyebrows, and Eastern ladies still apply it for the purpose of imparting by contrast a fictitious freshness to the complexion.

The principal ores of antimony are found in the mines of Bohemia and Hungary, in France, England, and in America. During the age of alchemy various other antimonial compounds were discovered; and an account of a process of preparing the metal was given by Basil Valentine in 1460.

Metallic antimony is met with abundantly in nature—native, combined with other metals: namely, with a little silver and iron in native antimony; with silver in antimonial silver; and with arsenic in arsenical antimony.

Antimony is also largely found combined with sulphur and the sulphides of other metals; for example, *per se*, in grey antimony, which generally contains copper, arsenic, and iron; with iron in Berthierite; with nickel and arsenic in nickeliferous grey antimony; with lead and traces of iron, copper, bismuth, and zinc in Jamesonite; with lead, copper, and iron in Bournonite; with lead and a trace of copper in zinkenite; with lead in antimonial lead glance; with silver and copper in melanglanz; with silver, copper, and iron in miargyrite; with silver in dark ruby silver, rhombohedral ruby blende; with silver and arsenic in light ruby silver; and with arsenic, silver, and iron in arsenical silver. It is also found, more or less, in the following argentiferous minerals: namely, with silver, copper, iron, and zinc, in weissgültigerz and graugültigerz; with copper and silver in antimonial grey copper, tetrahedral copper glance; and in very minute quantity, with copper, iron, silver, and arsenic, in kupfer-blende. It occurs as an oxide in white antimony, which is sometimes contaminated with sesquioxide of iron, and with sulphide of antimony in the red antimonial ore; also as antimonious acid in antimonial ochre.

Antimonial copper—*Antimonkupferglanz*, German—is composed, according to Schrötter's analysis, of—

	Centestimally.
Lead,	29·902
Copper,	17·312
Antimony,	16·644
Arsenic,	6·036
Iron,	1·404
Sulphur,	28·702
	100·000

This composition does not conveniently admit of being represented by a chemical formula.

The principal sources of the antimonial ores are the Continental mines, very little of the metal being found in this country. The ore submitted to reduction is the sulphide of antimony—grey antimony—of which from 600 to 1000 tons are annually imported into England.

In the laboratory the metal is prepared in a variety of ways; if 8 parts of powdered sulphide of antimony be intimately mixed with 6 parts of cream of tartar (potassium acid tartrate), and 3 of nitre, and the mixture be thrown in small portions into a red-hot crucible, and kept at redness for some time, a metallic button collects at the bottom. The antimony thus obtained is, however, impregnated with small traces of iron, and resembles the better sort of the crude metal found in the market.

When the sulphide of antimony, mixed with some charcoal to prevent the caking of the mass, is heated in contact with air, the greater part of the sulphur is expelled and antimonious oxide (Sb_2O_3) formed; this may now be reduced to metal, either by fusing with an adequate quantity of black flux, or with the addition of ordinary soap; a button of impure metal remains. The purest antimony is procured by reducing this oxide either with powdered charcoal and alkali, or the potassium acid tartrate at a proper degree of heat.

As met with in commerce, antimony is more or less impure, in consequence of some imperfections or mismanagement in the process of its reduction. The contaminations are generally lead, iron, arsenic, and sulphur; but these may be separated by grinding the crude metal in an iron mortar, and fusing the powdered mass with one-tenth of its weight of saltpetre, which oxidizes all the foreign ingredients, as well as a part of the antimony, leaving the remainder in a pure state.

Antimony is very brittle, possesses a white silvery aspect and a plated crystalline texture, so that, when broken up, the fracture exhibits beautiful facets. It happens, also, that when the metallic button of antimony is suffered to cool in the crucible, the surface presents a fine stellated appearance. In consequence of this crystalline property, the alchemists considered the phenomenon symbolical of that mysterious luminary which was to guide them in their occult path to the discovery of a universal medicine, or the philosopher's stone.

At 800° Fahr. the metal fuses, and at a white heat it slowly but distinctly volatilizes in closed vessels; in a current of hydrogen, however, it distils with tolerable facility. If exposed to a stream of oxygen on ignited charcoal it burns brilliantly, evolving a white light, and is at the same time converted into the tetroxide (Sb_2O_4), which is eliminated in the form of a thick whitish smoke. Should a globule of the metal at a high temperature be dropped from an eminence upon a board or plate of iron, the mass subdivides into numerous smaller globules, which hop along the plane in a combustible state, marking the course they take by a white streak or line of the tetroxide.

Antimony is not sensibly affected on exposure to the air at the ordinary temperature; its surface becomes slightly tarnished, but does not rust. If exposed to the air during fusion, rapid oxidation takes place.

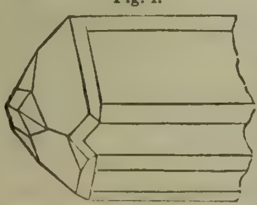
Hydrochloric acid dissolves antimony with the evolution of hydrogen and the formation of the trichloride ($SbCl_3$); concentrated sulphuric acid oxidizes it, sulphurous acid being at the same time evolved; but if the acid be diluted with water it does not dissolve it. Nitric acid, even when very dilute, rapidly attacks antimony, and converts it into a white insoluble powder which is the trioxide, tetroxide (Sb_2O_4), or the pentoxide (Sb_2O_5), according to the strength of the acid and the time of digestion. Aqua regia converts the metal into the trichloride.

The specific gravity of antimony is 6·712, and its specific heat, according to Regnault, is 0·05077.

For preparing the metal on a large scale, the trisulphide (stibnite, or grey antimony ore, Sb_2S_3) is generally employed, as well for the abundant produce which it yields, as on account of its reduction being more easily effected than that of any other ore of the metal, with the exception of the native oxide; the latter, however, is never met with in sufficient quantity, and consequently is seldom used.

There are two varieties of stibnite, the massive and the fibrous: the former presents a long columnar composition, and the latter is distinguished by its plumous, woolly, or felt-like appearance; it is of a light lead colour, sometimes dull externally, and often iridescent.

Fig. 1.



The mineral is met with in crystals of the rhombic prism (Fig. 1), which are sometimes aggregated laterally. Before the blowpipe, on charcoal, sulphide of antimony fuses and is absorbed, giving off at the same time sulphurous acid and white fumes of the trioxide of the metal.

The most celebrated localities productive of this mineral are Felsobanya, Chemnitz, and Cremnitz, in Hungary, whence the grey antimony is procured; Dumfriesshire in Scotland, where the fibrous and laminated variety is found; and Cornwall, where the massive sort is raised. Other varieties of the sulphide are also to be found, at Magurka in Hungary, at Freyberg and Braunsdorf in Saxony, and at Stolberg in the Hartz.

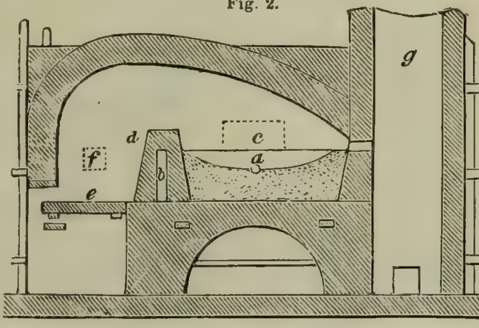
Manufacture of Antimony on the Large Scale.—Many of the operations in the preparation of antimony on the large scale are the same as those which will be mentioned hereafter, when describing the dry assay of the antimonious compounds. The method most commonly followed is, first to convert the sulphide into oxide, and then to reduce with cream of tartar.

The sulphide of antimony is deprived of its sulphur, and oxygen substituted by heating with free access of air, as in the annexed equation:—

$$\begin{array}{ccccccc} \text{Antimonious sulphide.} & & \text{Oxygen.} & & \text{Antimonious oxide.} & & \text{Sulphurous oxide.} \\ Sb_2S_3 & + & 9O & = & Sb_2O_3 & + & 3SO_2 \end{array}$$

This change is conducted in a reverberatory furnace, where the comparatively large amount of oxygen required to displace the sulphur (which is also oxidized), is derived from the abundant current of air flowing over the heated mineral. During the roasting the attendant should be mindful of the great volatility of trisulphide of antimony, and regulate the heat so as to prevent the loss of material which would attend the application of a too elevated temperature. The charge of stibnite must be well stirred with an iron slicer or rake during the roasting, to insure every part coming in contact with the atmosphere. When properly roasted the mass has a greyish-white appearance.

Fig. 2.



Having obtained the oxide in the manner described, it is intimately mixed with about a tenth of its weight of cream of tartar, and reduced in large earthen crucibles, heated in a wind furnace, when the following decomposition takes place:—

$$\begin{array}{ccccccccccc} \text{Antimonious oxide.} & & \text{Potassium acid tartrate.} & & \text{Antimony.} & & \text{Potassium carbonate.} & & \text{Carbonic oxide.} & & \text{Water.} \\ Sb_2O_3 & + & 2KC_4H_5O_6 & = & 2Sb & + & K_2CO_3 & + & 7CO & + & 5H_2O \end{array}$$

The antimony thus obtained is tolerably pure, and is ready for market. Iron is the principal, and often the only impurity present.

At Linz, in Germany, a furnace, similar to that represented in the annexed cuts, was constructed for the reduction of antimony at one operation. Fig. 2

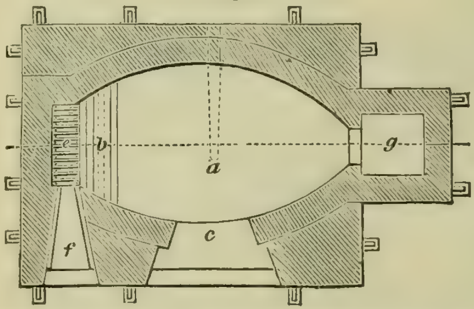
shows a vertical section; the bed is concave, and is constructed of sand and clay well consolidated; at its middle a pipe, *a*, forms a canal for the fused metal to flow out as soon as produced, and which is closed by heavy ashes. *b* is the air channel in the bridge *d*, and *c* is a door through which the prepared ore is introduced and the residuary slag abstracted. The fire is shown at *f*; *e* is the grate and *g* the chimney.

Fig. 3 is a plan of the furnace, wherein the same letters indicate the same parts.

Sulphide of antimony is dressed for reduction by mixing it with the proper quantity of iron, or iron scales, and alkaline carbonate: 2 or 3 cwts. of ore require from eight to ten hours' heat for reduction; but the metal obtained in this way is very impure, and is therefore remelted in portions of from 20 to 30 lbs. in crucibles. These ase covered over with ground charcoal, and heated in a reverberatory furnace.

The metal obtained by this process contains considerable quantities of iron, sulphur, and frequently arsenic, lead, and copper. These bodies deteriorate its quality, even for the arts, and of course it cannot be employed in medicine while the smallest trace of arsenic is present. It is therefore imperatively necessary to subject the crude antimony to purification. For this purpose it is fused with ⅛ part of antimonious sulphide, and an equal weight of sodium carbonate, in a hessian crucible for one hour. On breaking the crucible after cooling, the metal is carefully separated from the slag, and submitted to a second fusion with 1½ part of the carbonate. Sometimes a third fusion is required; but in this case it is to be performed with 1 part of the alkaline carbonate. Should there be lead, it remains in the antimony after the second fusion, although the other metals may be completely removed; and from its great fusibility, slight portions are retained even after the third operation.

Fig. 3.



If arsenic be absent, a part of the metallic antimony is oxidized and remains in the slag; but very little, if any, of the metal is thus acted upon whilst arsenic is present.

It has been found that 100 parts of the crude metal and 6 parts of the sulphide yield 94 of pure antimony. It is necessary, when larger quantities of iron are present, to add proportionally more of the sulphide of antimony; for unless there be sufficient sulphur to combine with the whole of the iron, the arsenic cannot be oxidized.

Wöhler recommends deflagration of 10 parts of the metal with 12 of saltpetre, and 10 of carbonate of soda; the arsenic is oxidized, and forms potassium arsenite, and the antimony is at the same time converted into potassium antimoniate by this treatment. On boiling the fused mass with water, the arsenical compound is dissolved, leaving the antimoniate, which is collected, washed, dried, and reduced in the usual way with charcoal in an earthen pot.

The metal obtained by this means still contains copper and iron.

According to Berzelius, the impurities are removed by fusing 2 parts of the metal (finely powdered) with 1 part of the trioxide of antimony; the iron, copper, and arsenic are oxidized, and remain in the slag; in this case the lead, should any be present, is still combined with the antimony. Muspratt thinks it better to fuse rather more than 4 parts of antimony with 1 part of manganese dioxide, and to subject the regulus so obtained to a second fusion with one-tenth of its weight of sodium carbonate.

As the stibnite is nearly always found associated with seams of silicious and calcareous impurities, a preliminary operation is necessary in order to separate it from its gangue; this process is called *eliquation*.

Fig. 4.

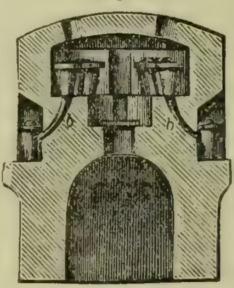
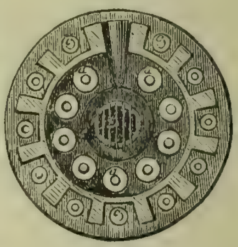


Fig. 5.

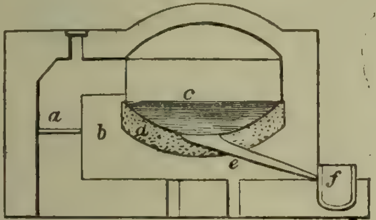


Any difference that exists in the manner of eliquating crude sulphide of antimony is chiefly in the furnace employed. In Hungary the ancient method, viz. that of roasting the ore in large pots or crucibles, is still practised. These pots are furnished with an aperture at their bottom, opening into a smaller one, which is embedded in the ground. A cover is appended to the upper pot, which may be luted down after the vessel is charged. These pots are placed in a circle with a furnace in the centre, the heat from which passes freely under the bottom and round the body of each pot.

Figs. 4 and 5 are drawings of this arrangement; the former is a section of the elevation, and the latter a plan, showing the position of the crucibles round the fire. *a a a* denote the pots in which the crude ore is heated, and *c c c* the smaller pots which receive the liquid sulphide; *d* is the fire-grate. In the elevated section, the relative position of these crucibles is comprehensively shown, with their connecting tubes, *b b*; both crucibles and tubes are made of earthenware.

The furnace employed for the fluxion of the crude sulphide at Vendée, in France, is represented in Fig. 6, where, instead of several pots being placed round the fire, the bed of the reverberatory, which is connected with a receiver for the purified trisulphide, supplies their place. In the figure, *a* represents the fire-place, *b* the bridge of the furnace, *c* the concave hearth, lying on the substrata, *d*; *e* is the pipe which issues from the bottom of the furnace hearth, and carries the liquid products along to the recipient, *f*. The furnace is heated by the flue passing around the body, and the charge is introduced through an opening in the dome, not shown in the woodcut. This construction of furnace is far preferable to the preceding one, both for the simplicity of its arrangement and the advantage of its being reverberatory. When moderately rich ores are subjected to purification, the charge, which is usually from 8 to 10 cwts., yields from 4 to 5 cwts. of the purified trisulphide, with a consumption of about 25 cubic feet of wood as fuel. Three such charges may be worked off in the long days of summer.

Fig. 6.



The best furnace for the separation of the sulphide of antimony from its matrix, is that in use at the extensive mines of Malbosc, in the Ardèche Department in France; it is sketched in the subjoined engravings. Fig. 7 is the plan of the furnace on a line with the flues *f g h*, which issue from the several fires, and the grates *a b c*, whereon the ignited fuel is supported. These grates are 4½ feet in length by about 1 foot in breadth, and are separated by two square galleries, *d* and *e*, running parallel through the furnace, and protected from the direct action of the fire by walls, having the alternate openings, *f g h*, serving as flues, to conduct the heat into the galleries, which are closed by the iron doors, *i i*, at each end.

Fig. 7.

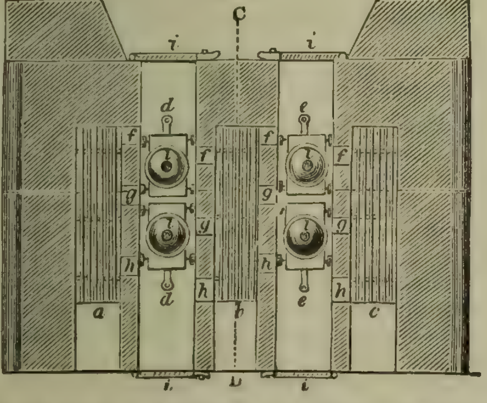
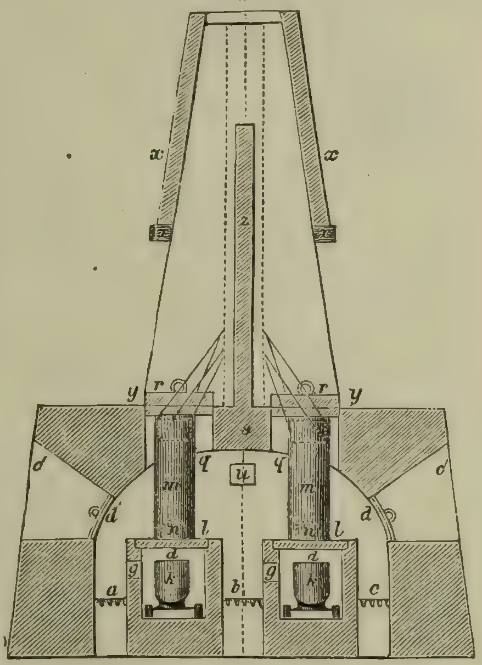


Fig. 8, the section of the furnace explains the nature of the arrangement.

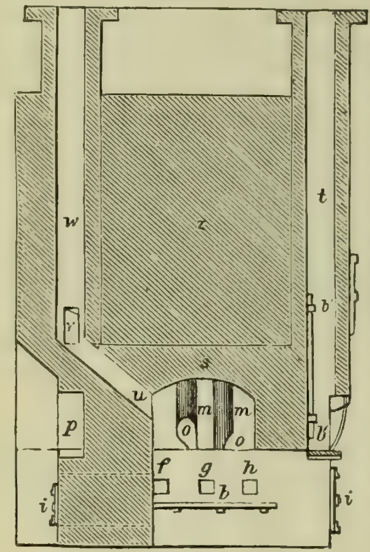
In this drawing all the parts before referred to are indicated by the same letters. The galleries, *d d*, hold two large crucibles, *k k*, of cast iron; covered with clay luting in order that they may not adhere to the sulphide of antimony which flows into them. To each of these crucibles a set of wheels, running on parallel bars of iron, leading into the furnace, is affixed. In this way the crucibles are charged, placed in the furnace, and withdrawn with facility. Both galleries are covered with flat tiles of firebrick, *l l*, on which the conical fire-clay cylinders, *m m*, rest. The antimony ore for fusion is introduced into these fire-proof cylinders, and the product, purified by fusion, is received in the lined crucible beneath the cover, *l l*, through the connection, or small opening, *n*, at the base of the cylinders. *q q* is the arch of the furnace through which the cylinders ascend, by openings somewhat larger than their outer diameters: these orifices are closed at the top by clay covers, *r r*. The arch at the top, *s*, is constructed cylindrically, forming a double cross arch.

Fig. 8.



After the flame from the fire has played round the cylinders containing the mineral, it passes through three openings and flues into the chimney, *t*—Fig. 9. Two of these openings are indicated by the letters *u* and *v*, in this figure, which is a section of the elevation following the line, C D, of Fig. 7; these flues are provided with valves. *w* is a chimney for carrying off antimonious vapours which may be expelled from the cylinders while drawing out the slag and exhausted ore. Another chimney, *x*, begins above *y y*—see Fig. 8.—where the cylinders are charged; a partition, *z*, divides this chimney into two parts, so that the workman, while operating on one side, is not inconvenienced by the fumes of the other. *o o* are orifices several inches in height, by which the cylinders may be reached from the front and back part of the furnace by conical openings, such as *p*, in the walls; the openings, *o o*, are closed during the working with clay stoppers, *n n*, seen in the preceding figure, which are removed at the end of an operation. *a′* and *b′ b′* are iron and wooden beams and bands to brace the chimneys. *c′ c′* are conical arches on both sides of the furnace, closed with well-fitting plates, *d′ d′*; through these the interior of the furnace may be examined, and repairs made when required.

Fig. 9.



Each cylinder is charged with 490 lbs. of ore, previously warmed on the arch, the coarsest and richest of which is placed at the bottom of the cylinders. As soon as the melting of the ore is completed, the impurities remaining are withdrawn through the openings, *o o*, and a fresh charge is introduced. The trisulphide of antimony produced should have a bluish colour; if it possesses a reddish appearance, it is indicative that too great a heat has been applied. When the iron receivers are three-quarters full, they are drawn out and allowed to cool, and the lump of crude antimonious sulphide is removed. Fresh charges are put in every three hours, and about 1 cwt. of the trisulphide is obtained at each process, when the furnace is in good working order, On an average, the cylinders last about twenty days.

It is of extreme importance that the heat be not too great, since at a white heat antimony is completely volatilized. Nor should the ore be too finely pulverized, as in this case the melted sulphide cakes together with the gangue, and is very difficult to separate. The residues always contain from 10 to 12 per cent. of antimony, partly in the form of trisulphide, partly as trioxide.

The product of the preceding operations is next roasted in a reverberatory furnace to expel the whole of its sulphur, and to produce instead the trioxide of the metal; the latter is subsequently reduced by mixing it with about 20 per cent. of charcoal, saturated with a strong solution of carbonate of soda. According to Berthier, 70 per cent. of good metal may be procured from the ordinary product of fluxion of the crude sulphide, when mixed with 60 parts of iron scales from the hammer or rolling mill, 45 to 50 of carbonate of lime, and 10 to 12 of powdered charcoal, and the mixture heated to fusion in the ordinary way. Iron is often found in considerable quantities in the antimony procured from this mixture; and therefore, unless subsequently purified, it cannot, in many instances, be advantageously employed.

Uses in the Arts.—Antimony is chiefly used as an ingredient in making alloys, such as type-metal, Britannia-metal, plate-pewter, and various others. The typefounder uses two alloys of antimony, lead, and tin; the one composed of—

Tea lead,...	75	and the other	Tea lead,....	70
Antimony,..	20		Antimony,..	25
Block tin, ..	5		Block tin,....	5
	100			100

Stereotype metal is formed of

Tea lead,....................................	112 lbs.
Antimony,....................................	18 "
Block tin,....................................	3 "
	133

The best Britannia-metal is composed of:—

Tin,..	150 lbs.
Copper,......................................	3 "
Antimony, ...	10 "

Common Britannia-metal:—

Tin,..............................	140 lbs.
Copper, ...	3 "
Antimony,.........................	9 "

Britannia-metal for Castings:—

Tin,.............................	210 lbs.
Copper,..........................	4 "
Antimony,........................	12 "

Britannia-metal for Lamps:—

Tin,..............................	300 lbs.
Copper,...........................	4 "
Antimony,.........................	15 "

A higher proportion of antimony is sometimes used. Copper is added to give colour. The chief use of antimony in making stereotype plates is, that besides hardening them, it causes expansion of the alloy in cooling, and as the cooling next the type is latest, the expansion causes the metal to fill every interstice, and beautifully sharp casts result. Nearly every manufacturer uses different proportions of antimony according to the quality of his tin. The usual practice is to test a small quantity of the tin with antimony, before casting on the large scale.

Antimony imparts a peculiar beautiful red colour to copper, varying from rose red, with little antimony and much copper, to crimson and violet when the proportion of the metals more nearly approach equality. For this reason antimony is sometimes added to brass to improve its colour.

Antimony is used for the preparation of concave mirrors. It gives a finer texture to the mass, on which account it takes a better polish. It is also an ingredient of bell metal, being supposed to increase the clearness and strength of the sound, besides improving the colour of the bells.

From its easy fusibility, it is used to promote this quality in many alloys which are employed for artistic or manufacturing purposes.

Antimony forms compounds with oxygen, sulphur, and chlorine, in various proportions, as seen in the following table:—

Antimonious oxide (trioxide of antimony), ...	Sb_2O_3.
Antimonoso-antimonic oxide (tetroxide, or neutral oxide of antimony), ...	Sb_2O_4.
Antimonic oxide (pentoxide, or acid oxide of antimony), ...	Sb_2O_5.
Antimonious sulphide (trisulphide of antimony),..	Sb_2S_3.
Antimonic sulphide (pentasulphide of antimony),.	Sb_2S_5.
Antimonious chloride (trichloride of antimony),..	$SbCl_3$.
Antimonic chloride (pentachloride of antimony),..	$SbCl_5$.

It also unites with bromine, iodine, and selenium.

Of the preceding compounds, the trisulphide, trichloride, and trioxide, are the only important bodies in a manufacturing point of view. They are, with the exception of the trisulphide, which is employed to prepare the metal, almost exclusively used in medicine. These will now be described.

ANTIMONIOUS SULPHIDE.—*Trisulphide of antimony, anhydrous sulphantimonious acid, crude antimony, antimony ore, schwefelspiessglanz, anderthalb, schwefelspiessglanz rohes antimon*, German; *stibium sulphuratum nigrum, lupus metallorum*, Latin. Formula, Sb_2S_3.

Having already described the principal use of this antimonious compound, and the method followed for purifying it, nothing further remains but to add a few words on the manner in which the pure trisulphide is prepared for other purposes. The trisulphide hitherto described contains, even after careful fluxing, variable quantities of sulphides of iron, lead, copper, and arsenic; hence the black streak which the fused compound makes, instead of a blackish red, which is formed by the pure substance. Crystalline antimonious sulphide may be prepared by fusing 13 parts of pure antimony and 5 of flowers of sulphur (sublimed sulphur) in a crucible, the mixture being introduced by degrees and at short intervals. After the whole has been fused the crucible is taken from the fire and inverted, to allow the melted sulphide to flow out. The whole of the metal may not be decomposed in this operation, but those portions which have escaped the action of the sulphur are easily removed.

Pure trisulphide of antimony, as thus prepared by the first method, has a steel-grey colour, a shining metallic lustre, and a fibrous crystalline texture; it is brittle, and gives a reddish-black streak upon paper; it is very fusible, but less so than the metal, boils at a high temperature, and partially distils in a current of gas. When heated to whiteness in a crucible it loses from 10 to 12 per cent. of its weight of sulphur; heated in the air, it suffers decomposition, giving off its sulphur in the form of sulphurous acid, and absorbing oxygen, which converts it into trioxide of antimony.

A current of hydrogen gas passed over it at a low red heat completely desulphurizes it, leaving pure metal. This property of hydrogen, that of depriving it of sulphur at a red heat, is possessed also by many metals, of which the most energetic is iron. When exposed with charcoal to a white heat, the antimonious sulphide is likewise reduced to metal.

When the trisulphide and trioxide of antimony are fused together, combination takes place, without either of the compounds suffering decomposition.

Its chief use, besides its employment as a source for the production of the metal, is for pharmaceutical preparations, chiefly tartar emetic.

Amorphous Trisulphide of Antimony; Kermes Mineral; brown-red sulphide of antimony; Pulvis carthusianum, sulphur stibiatum rubrum. — Amorphous trisulphide of antimony may be made by various processes. For instance, by conducting a stream of sulphuretted hydrogen gas through a concentrated solution of tartar emetic (potassio-antimonious tartrate, $K(SbO)C_4H_4O_6$), an orange-red precipitate is formed, which is the sulphide in question. When *kermes mineral* is digested for some time with tartaric acid, any antimonious oxide or potassium salt which may be present is removed, and pure trisulphide of antimony remains. Again, by digesting a mixture of 1 part of crude trisulphide of antimony with 1 part of pearl ash (crude potassium carbonate), 1½ of slaked lime, and 15 of water, in a closed vessel for two hours. During the digestion a soluble double sulphide of antimony and alkali is formed; and on adding sulphuric acid to decompose the alkaline sulphide, sulphide of antimony falls down; this precipitate is then filtered, washed with sulphide of hydrogen water, and dried.

FUCHS obtained pure amorphous sulphide by fusing the grey trisulphide of antimony, and then cooling the vessel suddenly by immersion in cold water. LIEBIG, as will be seen in a subsequent process, converts the crystalline native sulphide into the amorphous variety by dissolving it in an alkaline ley, and precipitating by an acid; or by igniting 1 part of antimony with 2 parts of a mixture of 1 part nitre with 2 parts cream of tartar, extracting with water, filtering whilst hot, and precipitating the filtrate with an alkaline carbonate.

Mineral kermes varies in composition according to the process by which it is prepared. Some of the processes yield pure trisulphide of antimony, others a compound of antimonious sulphide and oxide, whilst that investigated by BERZELIUS and ROSE contained sulphantimonite of potassium or sodium.

The oldest method of making mineral kermes is that described by LA LIGÉRIE. The grey sulphide is powdered finely, and then boiled with an alkaline carbonate, and the filtered solution allowed to cool. This method is still given in the Prussian Pharmacopœia. The crystalline grey sulphide is much less soluble in alkaline carbonates than the amorphous precipitated red sulphide. LIEBIG therefore recommends that 1 part of finely powdered grey sulphide should be boiled with 1 part of potassium hydrate and 30 parts of water for one hour, and the filtrate precipitated while still hot by dilute sulphuric acid. The mixed salts are then divided into 3 parts, each of which is washed with water, in a separate vessel, by subsidence and decantation, and afterwards collected on a filter. The precipitate collected on the first filter is then thrown by successive portions into a boiling solution of 1 part of dry carbonate of soda in 34 parts of water, and the whole boiled for an hour; and the solution (which need not be filtered, since nothing remains undissolved) is then slowly cooled to separate the kermes. The solution poured off from the precipitated kermes is again raised to the boiling point, and the contents of the second filter added to it, and similarly with the third filter. The kermes deposited after the second boiling has usually the finest colour. The kermes thus prepared amounts, after washing with cold water and drying, to half the quantity of the grey sulphide used. It must be regarded (according to LIEBIG) as $Sb_2O_3 2Sb_2S_3$ (a composition similar to that of red antimony ore), but it still contains from 1 to 1·5 per cent of soda.

Kermes free from antimonious oxide may be prepared by the following process:—A mixture of 1 part of finely powdered trisulphide of antimony, with 1 part of potassium carbonate, 1·5 part of potassium hydrate, and 15 parts of water, is digested in a close vessel for two hours; the filtrate diluted with a large quantity of water, and precipitated by sulphuric acid; the precipitate boiled with dilute sulphuric acid (to decompose the potassium sulphide present), and the residue washed with water.

H. ROSE gives two processes. The first is to heat slowly 1 part of pure potassium or sodium carbonate and 2¾ parts of grey sulphide of antimony, in a covered crucible, till the mass fuses. This mixture is boiled with water, and filtered; the compound sulphide dissolves out and, on exposing the solution to the air, precipitates as the liquid cools. After the first filtration the residue is heated with water, or with the clear mother liquid left after a previous deposit of kermes; a further quantity of the compound is dissolved out, which separates from the liquid, as before, as soon as the whole becomes cold. When the boiling solution has been thus treated three or four times in succession, there remains an insoluble substance, consisting mainly of a trisulphide and trioxide of antimony, Sb_2S_3,Sb_2O_3.

The quantity of kermes thus obtained is much greater than that produced by boiling grey sulphide of antimony with carbonate of soda, because more sulphide of antimony is decomposed by fusion; but the kermes has more of a yellowish brown colour, and contains a larger amount of antimonious oxide (Sb_2O_3), though in variable proportions. The more rapidly the kermes is collected in the filter after cooling, the less is the quantity of oxide mixed with it. Besides antimonious oxide, the kermes also contains a compound of potassium or sodium sulphide, with pentasulphide of antimony (K_2S,Sb_2S_5), potassium sulphantimonate. Hence such a kermes, if prepared with sodium carbonate, yields sodium chloride (about 8 per cent.) when decomposed by chlorine gas. And the liquid from which the kermes has been deposited contains carbonate of soda, sodium sulphantimonate (Na_2S,Sb_2S_5), and sulphantimonite (Na_2S,Sb_2S_3). On evaporation it yields—first, crystals of sodium antimonate, and then of carbonate of soda. Addition of sodium bicarbonate decomposes the sulphantimonite remaining in solution, and brownish red kermes are deposited. DUFLOS remarks that the larger the proportion of alkaline carbonate, and the longer the fusion is continued, the smaller the quantity of antimonious oxide mixed with the kermes; but if too much alkaline carbonate is used no kermes is deposited. But if carbonic acid gas be passed through the solution, a brilliant kermes is precipitated in large quantity; and when the carbonic acid ceases to cause any further precipitation, the stronger acids, after expelling the carbonic acid, throw down pentasulphide of antimony (Sb_2S_5) from the liquid filtered from the kermes. Moreover, if the liquid precipitated by carbonic acid and filtered from the kermes be boiled with a fresh quantity of trisulphide of antimony, it deposits kermes on cooling, because the solution then contains carbonate of potash.

Another method is to fuse 2 parts of metallic antimony, 1 of sulphur, and 3 of carbonate of soda; or 16 parts of antimony, 3 of sulphur, and 32 parts of potassium carbonate; or to heat a mixture of from 3 to 4 parts of cream of tartar (potassium acid tartrate) ($KC_4H_5O_6$), and 1 part of grey sulphide of antimony, in a crucible, till the vapour of decomposed tartaric acid ceases to be given off.

The kermes which separates after boiling the crude antimony with alkaline carbonate in excess, and cooling the liquid, contains trioxide of antimony. After drying the precipitate the antimonious oxide becomes very apparent, especially if examined with the microscope, which shows its definite crystalline structure, interspersed with the amorphous flocculi of the kermes.

Kermes mineral was at one time in high repute on the Continent as a medicine, and indeed is still occasionally used in considerable quantities; in England it is largely used as a veterinary medicine. PEREIRA states that, when administered in small doses, it acts as a sudorific and liquefacient; in large doses, as an emetic and purgative. The uncertainty of its operation is, however, a great drawback; even when moderate action follows its use, it is doubtful whether it has any advantage over tartar emetic.

Hydrochloric acid decomposes kermes mineral with the formation of the trichloride, sulphuretted hydrogen being at the same time evolved and sulphur precipitated.

PENTASULPHIDE OF ANTIMONY.—*Antimonic sulphide, anhydrous sulphantimonic acid, golden sulphide of antimony, sulphur antimonii auratum* (Sb_2S_5).—This body is an amorphous yellowish-red powder, having a sweetish sulphurous taste and odour. It burns with a pale blue flame when heated in the air; heated in a closed vessel it is decomposed into trisulphide and free sulphur. When exposed to moist air it is wholly decomposed, sulphuretted hydrogen is evolved and trioxide of antimony formed. It is completely soluble in hydrochloric acid with the evolution of sulphide of hydrogen, a solution of trichloride of antimony being formed. When boiled with a solution of cream of tartar, tartar emetic is produced from the solution of the oxide of antimony contained in the precipitate. Its colour distinguishes it from the sulphur compounds already mentioned.

The commercial pentasulphide is often of a very bright colour; it is prepared by boiling the amorphous trisulphide with potassium hydrate and ground sulphur, and after filtering off the liquor, precipitating by means of an acid in the usual way Or, 4 parts of the trisulphide of antimony are boiled with 8 of lime and 80 parts of water, the liquor strained and precipitated by hydrochloric acid in the usual way. Or, 2 parts of the trisulphide may be fused in a crucible with 4 parts of carbonate of potassium and 1 of sulphur; the residue, when cold, boiled with 20 parts of hot water; the solution filtered and decomposed by a large excess of sulphuric acid.

The medicinal effects of this compound are more active than those of the kermes, on account of the larger proportion of teroxide of antimony which it contains. Its uses are as an alterative in chronic diseases, particularly cutaneous affections, glandular enlargements, rheumatism, and liver complaints.

Sulphantimonites.—Trisulphide of antimony combines readily with basic metallic sulphides. Many of these bodies are found as minerals, such as—

Zinkenite,	Pb_2S,Sb_2S_3
Myargyrite,	Ag_2S,Sb_2S_3
Antimonial copper glance,	Cu_4S,Sb_2S_3
Jamesonite,	$(Pb_2S)_3Sb_2S_3$
Feather ore,	$(Pb_2S)_2Sb_2S_3$
Stephanite,	$(Ag_2S)_6Sb_2S_3$, &c.

Livers of Antimony.—These are the artificial sulphantimonites of the alkali metals. They result from the fusion of trisulphide of antimony with alkaline carbonates.

Pentasulphide of antimony is a strong sulphur acid. It forms salts with most of the basic metallic sulphides, which have the composition $(M_2S)_3Sb_2S_5$ or M_3SbS_4.

ANTIMONIOUS OXIDE. *Trioxide of antimony* (Sb_2O_3), *valentinite, white antimony, antimony bloom*.—This substance is found as a mineral. It occurs in veins of the primary rocks in Bohemia, Saxony, and Hungary, in shining white crystals of the trimetric system, and also in Algeria in regular octahedra. The artificial crystalline trioxide is likewise found to be dimorphous. This compound was known to BASIL VALENTINE, who called it *flores antimonii.* In commerce it is termed indifferently *protoxide, sesquioxide,* and *flowers of antimony.*

It may be prepared in several ways. 1. On heating metallic antimony to the point of its combustion it burns with a bluish light, and if the crucible be reclined to one side to admit a current of air, small acicular crystals of trioxide will be observed on the upper part. 2. By adding metallic antimony in powder to sulphuric acid, evaporating the liquid to dryness, and then washing the dry mass, first with water and next with a weak solution of carbonate of soda, for the purpose of removing the last portions of sulphuric acid; after completely washing the residue a white powder remains, which is trioxide of antimony. 3. By digesting finely-ground grey sulphide of antimony in about four times its weight of hydrochloric acid, trichloride of antimony is formed and sulphide of hydrogen escapes with effervescence, the former of which is decomposed by carbonate of soda into trioxide of antimony, which precipitates, while carbonic acid is liberated, and the soda is converted into chloride of sodium by the chlorine of the antimonial compound.

The precipitated trioxide is collected upon a filter, washed well with water, and dried. For pharmaceutical purposes the Dublin college recommends the treatment of 20 parts of the powdered grey sulphide of antimony with 100 parts of hydrochloric acid and 1 of nitric acid; the acid and powder must be slowly brought together, and a gentle heat applied for some time, which may be afterwards increased, and the solution left to digest as long as any effervescence or escape of sulphuretted hydrogen is observed; and then the whole is to be boiled for an hour, the liquor filtered when cold, and the filtrate received in a vessel containing 1 gallon of cold water, which precipitates the basic trichloride of antimony. The oxychloride is collected, and washed with water till the washings cease to evince an acid reaction with litmus paper. During the washing of the precipitate the water is decomposed, its oxygen being retained by the antimony and antimonious oxide (Sb_2O_3) formed, hydrochloric acid being given off.

DUMAS directs the preparation of trioxide of antimony to be conducted as follows:—Heat pulverized antimony in a shallow vessel exposed to the air; when the oxidation has advanced, the metal takes fire and becomes incandescent, antimonic oxide (Sb_2O_5), mixed with some of the metal, being produced; the whole of the compound is now transferred to a crucible, in which it is heated to fusion, when the antimonic oxide is reduced to the state of trioxide by the excess of metal, which is found, with the fused mass, in a button at the bottom.

Trioxide of antimony is a white powder, fusible, and volatile at a red heat; when heated in close vessels it suffers no change, but is partly sublimed, and condenses in acicular or octahedral crystals on the cover, or upper part of the pot.

If the trioxide be kept in fusion, with contact of air, it is converted into pentoxide (antimonic oxide, Sb_2O_5); but if the air be excluded, it concretes into a silky crystalline mass, presenting a greyish appearance.

Water dissolves oxide of antimony in small quantity. Nitric acid and chlorate of potassium rapidly convert the trioxide into pentoxide; sulphur decomposes it in the heat into trisulphide, with the formation of water; and when heated to redness with charcoal, metallic antimony is obtained. Tartaric acid readily dissolves the antimonious oxide; acid tartrate of potassium acts similarly. In each case tartar emetic is produced.

TRICHLORIDE OF ANTIMONY.—*Butter of Antimony* ($SbCl_3$) is used to some extent in medicine, chiefly as a caustic.

On dissolving sulphide of antimony in hydrochloric acid, as before explained, trichloride of antimony is formed, with the evolution of sulphuretted hydrogen.

The action of the hydrochloric acid is greatly accelerated by mixing with it a small proportion of nitric acid. When the solution thus obtained is evaporated, the trichloride of antimony remains in the solid state. To prepare the pure salt, the hydrochloric acid solution of the trichloride should be evaporated in a porcelain dish, till it begins to crystallize on the dish being placed in a cold situation; the concentrated liquid is then transferred to a retort, and distilled until a drop of the liquid solidifies upon a cold surface; at this point the receiver is changed, and the remaining portion of the charge collected as pure.

It is white, semitransparent, crystalline, of a buttery consistence, and deliquescent in the air.

When added to water it gives a bulky white precipitate of powder of algaroth, which consists of trioxide, united with a portion of the trichloride, while hydrochloric acid remains in the solution.

Trichloride of antimony affords, with all the other reagents, similar reactions to those which distinguish the other salts of this metal.

Besides being used as a caustic, it is employed in the arts, especially by gunmakers, for the purpose of giving a yellow colour to gun barrels, and is called *bronzing salt.* It is used for this purpose in the state of solution, mixed with olive oil, and rubbed over the iron slightly heated, which is then exposed to the air till the desired colour is obtained. Sometimes, to quicken the effect, nitric acid is added. When bronzed, the surface of the iron is polished by a burnisher, or by wax, or by varnish composed of 2 ounces of shell-lac and 3 drachms of dragon's-blood dissolved in 2 quarts of spirit of wine.

QUANTITATIVE ESTIMATION OF ANTIMONY BY ANALYSIS.—The percentage of antimony in a mineral may be estimated from the amount of the trisulphide of antimony, the tetroxide or antimonate of antimony (Sb_2O_4 or SbO_2), or of the metal which it produces when operated upon with suitable reagents.

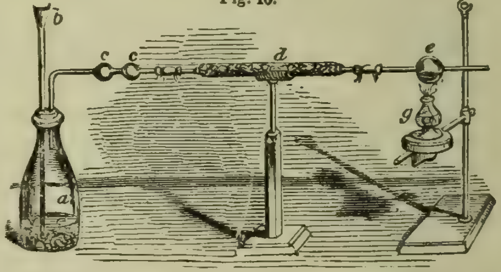
As Trisulphide.—A solution of the metal is obtained by treating the ore with strong hydrochloric acid, containing some nitric acid (if silver be absent). This solution is diluted with water, and should any turbidness ensue, tartaric acid must be added to dissolve it; or if the addition of this acid would interfere with the estimation of any other metal, hydrochloric acid is employed to effect the same purpose. Sulphuretted hydrogen is then transmitted through the liquid, until the solution acquires a strong odour of the gas, when the whole of the antimony will be converted into the red trisulphide. If antimony is the only metal present, the vessel holding the precipitate may be placed on a hot sand-bath till the excess of sulphuretted hydrogen is expelled. By this means the small quantity of trisulphide retained in solution by the excess of the gas is set at liberty. The solution is then filtered through a dried and tared filter, washed with water, dried in a water bath till the weight remains constant, and weighed.

As Tetroxide.—As the antimony in solution is often in a higher state of oxidation than the teroxide, especially if nitric acid has been employed, and as more or less of the sulphide of hydrogen is decomposed by the free acid of the solution before precipitation, the sulphide of antimony produced contains an excess of sulphur. In this case the excess of sulphur is to be extracted with carbon disulphide, and the antimony trisulphide introduced into a porcelain crucible, and then add—first, a few drops of strong nitric acid, and then fuming nitric acid in quantity about ten times the amount of the precipitate, and allow the acid to evaporate gradually in the water bath. The sulphur separates at first as a white powder, but is completely oxidized during the evaporation. The white residue is antimonic oxide with sulphuric acid, and may be converted into the tetroxide (Sb_2O_4) by ignition.

As the tetroxide is neither volatile nor decomposable by a red heat, it affords a very accurate means of determining antimony quantitatively. The Sb_2O_4 contains 79·22 per cent. of the metal.

As Metal.—Having ascertained the weight of the dry trisulphide produced by treatment with acids, and precipitating by sulphuretted hydrogen in the way already pointed out, a known quantity is to be taken and decomposed by heating in an atmosphere of hydrogen; sulphuretted hydrogen is evolved, and metallic antimony is left. A convenient apparatus for this purpose is seen in Fig. 10. The flask, *a*, contains water and a few bars of zinc; sulphuric acid is poured in through the funnel, *b*, in order to generate the gas, which escapes by a tube opening just below the cork of the flask, and which is provided with two bulbs, *c c*, where the greater part of the moisture carried away by the gas is condensed. To dry the hydrogen completely, it is conducted through another large tube, *d*, filled with fragments of chloride of calcium, and thence into the bulb, *e*, holding the substance to be reduced.

Fig. 10.



Before commencing the operation, the bulb, *e*, with its glass tubes attached, should be thoroughly cleaned, dried, and weighed, and the trisulphide of antimony then introduced. The bulbed tube and its contents are now reweighed, and the increase of weight is the quantity of the compound submitted to experiment. The various parts of the apparatus are next well connected by means of caoutchouc tubes, as seen in the figure, and the hydrogen generated; as soon as the apparatus is filled with the gas, a gentle heat is applied by means of a spirit-lamp, *g*, to the bulb containing the substance, till the reduction is completed. If the compound consists of trisulphide of antimony only, scarcely any sulphur is sublimed during the reduction, as it passes off in the form of sulphuretted hydrogen; but should the pentasulphide be present, sulphur will be sublimed at the same time that the remaining part unites with the hydrogen and escapes. The sublimed sulphur is expelled by bringing the heat of the lamp gradually towards that part of the tube where it is deposited. When it is observed that no more sulphur condenses in the tube, and that sulphuretted hydrogen ceases to be evolved from the extremity, the apparatus is allowed to cool, but the current of hydrogen is still maintained for some time. As soon as the apparatus is perfectly cold, it is taken to pieces, the bulb-tube, *e*, wiped clean and weighed; the difference between the weight of the bulb-tube and substance before the experiment, and that which is now obtained, is the amount of sulphur in the antimony sulphide reduced, and the difference between the weight of the empty tube and its weight after the reduction, is the weight of the metal yielded by the sample operated upon.

Considerable care must be exercised in this reduction to arrive at accurate results: since it is almost impossible to prevent the sublimation of some of the antimony, if the heat applied be at all high; and on the other hand, if the temperature be too low, if it be too feebly applied, part of the sulphur remains without being expelled.

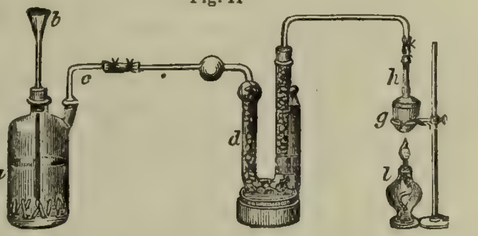
When antimony is alloyed with other metals, or associated with them in mineral substances, its amount may be determined, except when united to tin, by dissolving the substance in nitric acid, or in aqua regia containing an excess of nitric acid. The antimony is converted into trioxide of antimony, which precipitates, while the other metallic oxides are dissolved. Before the whole of the antimony is thrown down, however, it is necessary to decompose any trichloride that may be formed (when aqua regia has been used as the solvent), by evaporating the liquid with an excess of nitric acid. The residue is then thrown upon a filter and washed with water, dried, and its weight determined, after which a portion is taken and converted into tetroxide, or metal, as already described.

This method does not yield strictly accurate results, on account of the precipitated trioxide of antimony not being perfectly insoluble in nitric acid, and, therefore, the filtrate and washings always contain some traces of antimony; yet, for technological purposes, the results obtained are sufficiently correct.

H. Rose reduces the tri- and penta- sulphides of antimony in the apparatus given below, fig. 11. The hydrogen generator, *a*, contains zinc and water; *b* is a funnel-tube for adding sulphuric acid; *c*, a tube conveying the gas to the chloride of calcium tube and bulb, *d*, where it is divested of moisture. The gas, after leaving the chloride of calcium tube, passes to the crucible, *g*, containing the body to be reduced, through a small porcelain tube, *h*. Before the reduction commences, the crucible with the lid and its tube is balanced, and then the substance introduced, and the whole reweighed; the difference in the two weighings is that of the body taken. All the connections of the apparatus are now made air-tight, and the crucible attached; hydrogen is generated in the bottle, *a*, by pouring sulphuric acid down the funnel tube, *b*, and when the whole apparatus becomes filled with the gas, heat is applied by means of a spirit-lamp, *l*, to the crucible, taking all the precautions previously mentioned. When it is observed that no more sulphuretted hydrogen is evolved from the end of the tube, the heat is removed, but the current of hydrogen is maintained during the cooling of the apparatus, after which it is taken asunder, and the crucible with its contents weighed.

Arsenic being frequently associated with antimony in its ores and alloys, Noad suggests the following method for their separation:—Having dissolved the ore or alloy in aqua regia, sulphides of antimony and arsenic are obtained by saturating the solution with ammonia, and then adding ammonium sulphide containing an excess of sulphur; the whole is digested for some time, then filtered, and hydrochloric acid added to the filtrate in slight excess, to precipitate the dissolved sulphides. The precipitate is collected upon a dry tared filter, washed with water impregnated with a little sulphuretted hydrogen, and dried in the water-bath till all moisture is expelled, after which it is weighed.

Fig. 11



A portion of the mixed sulphides is then introduced into the bulb tube, Fig. 10, and a stream of hydrogen gas passed over it, while a proper heat is applied by the lamp; all the trisulphide of arsenic (As_2S_3), with the excess of sulphur, is expelled, leaving trisulphide of antimony, which is to be weighed.

Dry Assay of Antimonial Ores.—All the ores of antimony, for the purpose of assay, may be divided into two classes: those in which the metal is combined with oxygen or chlorine, and in which little or no sulphur is present; and compounds of sulphur and the metal.

All the ores belonging to the first class are very easily reduced (provided no earthy or silicious matters are present), by simply heating them to redness with finely-divided charcoal. The assay may be conducted in an earthen crucible; but as antimony is readily volatilized, care must be taken that the heat is not too high during the reduction. If the ore contain calcareous or silicious impurities, it is necessary to mix it either with 3 parts of black flux, or 1 of carbonate of soda, and $\frac{1}{4}$ part of charcoal finely ground. When the mixture is in a tranquil state of fusion, the crucible is to be withdrawn and gently tapped, to cause the small globules of antimony to unite, and form one button at the bottom.

The crucible is broken as soon as it gets cold, and the metallic button at the bottom carefully freed from adhering matter, by gently tapping it with the hammer, brushing off dust or other adhering matter, and weighed. Unless great delicacy of manipulation be observed when detaching the slag, portions of the metal will be removed on account of the brittleness of the antimony rendering it liable to the detachment of small particles, which, of course, would be so much loss.

Those ores which consist principally of trioxide of antimony, but which contain small quantities of sulphur, may be analyzed by the foregoing method; for as the sulphide yields to the black flux just half its combined antimony, a very small portion only can be retained in the slag.

Ores of the second class offer more difficulties than those just described. Their assay may be performed either by first roasting the sulphide, and subsequently fusing the oxide produced with black flux, or by directly treating the mineral, reduced to an impalpable powder, with finely-divided metallic iron or iron scales, and a little black flux, at an elevated temperature.

As the grey sulphide of antimony is very fusible and volatile, it requires much care and attention to roast it thoroughly, in order to expel the sulphur, and form the trioxide of the metal; to be successful, the temperature should be moderate, and the mass kept stirred with an iron rod or wire as long as any sulphurous acid is given off. It is then fused with 3 parts of black flux in the usual way, and a button of antimony is obtained.

The results of the dry assay of antimony ores are so very fallacious, that the process is now but seldom used.

ARSENIC.—*Arsenic*, French; *arsenik*, *arsen*, *scherbenkobalt*, *fliegengift*, *näpchenkobalt*, German; *arsenicum*, *regulus arsenici*, Latin; ἀρσενικὸν, Greek. Symbol, As; atomic weight, 75.

Arsenic is mentioned by Dioscorides and other authors who lived about the commencement of the Christian era. In their works the word was used to signify a reddish mineral composed of arsenic and sulphur, which was used as a medicine and in painting.

Arsenic is found native, but more often in combination with other metals and sulphur.

The distinct metallic characters of arsenic were discovered by Brandt in 1773, who gives the first accurate process for procuring it. He mixed white oxide (arsenious oxide or arsenious acid (As_2O_3) with potassium hydrate and ammonium chloride, and fused the mixture in a well-luted crucible. Its properties were further investigated by Macquer in 1746, by Munnet in 1773, and by Bergmann in 1777; but the latter took many of his facts from Brandt's paper.

Arsenic forms two native compounds with oxygen, namely, arsenious and arsenic acid. Orpiment and realgar, two of its sulphides, are also met with in the mineral kingdom. It has been discovered in minute quantity in a large number of mineral waters. Small quantities of arsenic are always found with iron ores, and frequently influence their quality. It is often found in combination with metallic sulphides, especially with the sulphide of iron, constituting arsenical pyrites ($FeAs + FeS_2$); and two kinds of arsenical iron are found, having the compositions FeAs and Fe_4As_3 respectively.

Arsenic is obtained as a bye-product from arsenical cobalt, cobalt glance, bismuth cobalt ore, nickel ochre, polybasite, red silver, arseniate of copper (of which several varieties are known), from euchroite, kupferschaum, erinite, scorodite, smaltine, cloanthite, nickel glance, copper nickel, arsenical nickel, arsenical fahl ores, &c.

The principal mines are those of Freiberg, Annaberg, Marienberg, and Schneeberg; Joachimsthal in Bohemia, Andreasberg in the Harz, Oravicza in Hungary, Kongsberg in Norway, Zmeoff in Siberia, where native arsenic is found in large masses, and at St. Marie-aux-Mines in Alsace.

The metal is readily prepared in the laboratory by mixing 1 part of pure arsenious acid with 3 of charcoal, or a mixture of charcoal and sodium carbonate in a crucible, on which another of a similar shape is inverted as a head, and applying a moderate heat, either in a furnace or over a lamp. By keeping the cover as cool as possible the metal will be found in the course of a short time to have sublimed, and to be adhering to the interior of the crucible in the shape of a brilliant metallic coating.

Arsenic is of a bluish-white colour, approaching steel grey, and has a crystalline structure. It is the most volatile of all metallic bodies, being completely vaporized without fusion at 365° Fahr. (185° C.). It is so brittle that it may be easily reduced to a fine powder by trituration in a mortar. Kept in water it suffers no alteration; but when exposed to the air it soon loses its lustre, becomes black, and falls to powder. When exposed to a moderate heat in free contact with air it sublimes in the form of a white powder, and at the same time emits its characteristic alliaceous odour, and is wholly converted into arsenious acid (As_2O_3). With limited access of air metallic arsenic is deposited in a compact brown mass, having a strong metallic lustre. If air be excluded and the temperature be high, the arsenic is deposited as a nearly white crystalline mass, which does not oxidize in the air even when heated to 80° C. The other forms readily pass into arsenious oxide by exposure to air.

Arsenic burns in air or oxygen with a pale blue flame into arsenious oxide (As_2O_3).

Orfila states that metallic arsenic, when swallowed, acts as a powerful poison, probably by being oxidized into arsenious acid.

The specific gravity of arsenic is between 5·62 and 5·96, its vapour density is 10·3995, air being unity: or 150, hydrogen being 1.

Heated with chlorine, arsenic ignites spontaneously, producing a brilliant white flame and forming arsenious chloride ($AsCl_3$). It is soluble in nitric acid and in aqua regia, and is converted by this treatment into arsenious or arsenic acid, according to the more or less prolonged action of the solvents. It enters into fusion with most of the metals, and by this union renders those which were malleable more brittle, and those before difficultly fusible more easily melted; it also confers a brightness upon the alloy, which often renders its presence in small quantities desirable.

The metal is prepared on the large scale by subjecting arsenical pyrites (Fe_2AsS_2) or arsenical iron ($FeAs + Fe_4As_3$) to sublimation in earthenware retorts, to which are attached receivers, wherein a piece of rolled sheet iron is generally placed, which collects the whole or greater part of the sublimated metal.

Arsenic forms two oxides—trioxide, anhydrous arsenious acid or arsenious oxide, As_2O_3, and pentoxide, anhydrous arsenic acid or arsenic oxide, As_2O_5.

Arsenious Acid.—*Arsenious anhydride*, *Arsenious oxide*, *Anhydrous arsenious acid. Acide arsenieux*, French; *arseniksäure*, German; *acidum arseniosum*, Latin. *White arsenic*, *white oxide of arsenic.* Formula, As_2O_3.

This compound is formed, as previously stated, when arsenic is heated in the open air; it sublimes in white fumes, and when collected constitutes arsenious acid. It is usually in the form of a compact white cake; but it may also be obtained crystallized in octahedra by cooling the vapour so quickly that it solidifies at once without becoming semiliquid. It has an acrid taste, which leaves an impression of sweetness; but it is one of the most virulent poisons known. Arsenious acid occurs native as Arsenite or Arsenolite.

Fig. 1.

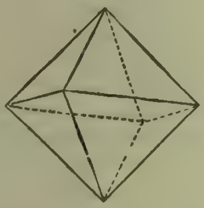
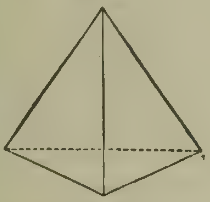


Fig. 2.



Arsenious acid is soluble in boiling water to a moderate extent, but considerably less so in cold; it is also soluble in alcohol and oils. Regarding the solubility of arsenious acid, Guibourt found that the crystallized acid required 104·17 parts of water at 60° Fahr. (15°·5 C.), and the amorphous 80 parts. Boiling water dissolved 9·68 of the former, and 11·47 parts of the latter; the solutions, upon being cooled at 60°, retained 1·78 of the crystalline, and 2·9 of the amorphous. Both solutions communicate a feeble acid reaction to blue litmus paper.

Arsenious acid is found in two distinct conditions —crystallized and amorphous. The crystallized acid often assumes two forms; the octahedron and tetrahedron.—Figs. 1 and 2. Wöhler has observed that the acid assumes the form of hexahedral plates, derived from the right rhombic prism; hence it appears to be dimorphous, which seems connected with the peculiarities of the opaque and vitreous state of the acid.

Vitreous arsenious acid, when recently prepared, is in the form of large, glassy, colourless, transparent cakes; it is sometimes of a yellowish colour, and in concentric laminæ formed by successive sublimations. By exposing these transparent cakes to the air, they are readily covered with a white coating, and lose their former transparency. This change is gradually extended to the centre, so that the fracture has an enamel-like appearance; occasionally the cakes crumble down into a friable mass. The reason of this change has been ascribed by Kruger to the absorption of water, as, according to that chemist, no change takes place in perfectly dry air; he ascertained that the acid increased in weight, though not more than $\frac{1}{100}$th of the whole mass.

Pereira kept arsenious acid in a sealed tube for two years without any change being noticed, but on cracking the tube the transparency of the inclosed acid was in a very short time lost.

A singular property of arsenious acid observed by Rose is, that when the vitreous acid is dissolved in hydrochloric acid, and allowed to cool slowly, vivid flashes of light are emitted from the crystals as they form. The phenomenon does not attend the crystallization if the opaque acid is dissolved in the acid liquor, neither will it succeed if the crystals deposited from the vitreous substance be redissolved in the acid, and suffered to cool as they acquire the property of the opaque acid; the production of the light seems to be connected with the transition from one modification to the other.

Heated on charcoal before the blowpipe, arsenious oxide emits the peculiar characteristic arsenical odour; when mixed with carbonate of soda and charcoal, and the compound subjected to heat in a glass tube, it yields a ring of metallic arsenic which condenses on the cold part of the tube. Arsenious acid is decomposed at an incipient red heat by hydrogen, carbon, and many of the metals.

Sulphuretted hydrogen produces, in solutions of arsenious acid, a lemon-yellow precipitate of trisulphide of arsenic (As_2S_3), which is very characteristic of this body, the yellow tint being observed when $\frac{1}{10000}$th of the acid is present, and a precipitate becoming visible in an acidulated solution of 1 part of arsenious acid in 80,000 parts of water. Excess of lime-water occasions a white precipitate in a liquid containing about $\frac{1}{500}$th of arsenious acid. Ammonio-sulphate of copper gives an apple-green precipitate in a solution of arsenious acid, thus indicating about a $\frac{12}{1000}$th part of the acid; and according to Reinsch, when a slip of bright copper leaf is boiled in an aqueous solution, acidulated by hydrochloric acid, a grey film of arsenic is deposited upon the copper, showing the presence of less than $\frac{1}{100,000}$th part of the acid. Nitrate of silver gives with it a yellow precipitate.

Arsenious acid unites with most metals, with which it forms salts, called *arsenites.* With oxide of copper it gives compounds much used as pigments, all which will be hereafter described.

Manufacture of White Arsenic, or Flour of Arsenic.—This is the arsenious acid in the form of a powder, white and fine as flour. The modes of its preparation in England and on the Continent somewhat differ. In England its manufacture is carried out in Cornwall and Devon, and it is also produced at Swansea. From the Mineral Statistics of the United Kingdom for 1873, we learn that in that year the quantity made was 5448 tons, of a value of £22,854, the greater part of what was thus returned being crude arsenious acid. Since then the manufacture has been stimulated by a larger demand and increased price; the refined product which in 1873 was sold at £6 8*s.* 9*d.* per ton, has since been sold at £15 per ton, and even quoted at £18 to £20 per ton.

The only mineral from which in this country arsenious acid is in any quantity prepared, is arsenical pyrites or mispickel, the formula of which is $FeAs + FeS_2$; this gives 46·58 per cent. of arsenic, while by analysis about 43 per cent. is obtained. This arsenical pyrites is associated with various other metallic minerals, the presence of which requires special attention. Thus, ores are raised which may contain any or all of the following:—Arsenical pyrites, iron pyrites, copper pyrites, tinstone, wolfram, blende, and galena, besides quartz and other non-metallic minerals. It will depend on its associates whether the arsenic will be the main end of the processes, or whether it shall be counted but a bye-product. The same circumstances will determine what shall be the preliminary mechanical preparation of the ore. Thus, where tinstone is present in any quantity that will repay its separation by the mechanical means always employed for that purpose—in a proportion, it may be, of less than 1 per cent. even—the ore is stamped to a fine state of division, and undergoes certain of the washing processes peculiar to the preparation of tin ore before it is considered fit to be treated for arsenic, and afterwards the residue is again mechanically treated for tin. Where there is a mixture of copper ore and arsenical pyrites, the material is generally separated by eye and hand into two classes—one from which copper will afterwards be extracted, and one which contains so little copper that its extraction would not be profitable; the only difference in their treatment is in the destination of the residue, that of the latter class being considered as refuse. These copper and arsenic ores are crushed between rolls, and may be sent through a sieve with apertures of 1¾ inch or less.

The percentage of arsenic in the ores treated varies much. At one extreme are those tin ores for which calcining is necessary for the sake of the tin, and of which the arsenic is but a bye-product; at the other is ore which contains little but quartz and arsenical pyrites, the latter in quantity that will well repay extraction. In this class, and in ore which contains both arsenic and copper, the arsenical pyrites may vary from 12 to 30 per cent. It is useful to be able to determine the percentage of arsenic present in the ore, readily if roughly. At many mines a very rough and ready plan is followed:—100 or 200 grains of the ore is heated over the fire in an iron ladle till all the arsenic and sulphur are burnt away; the weight of the residue is then compared with the original weight, and from the difference the richness of the ore is judged. The proportion of pyrites other than arsenical in the ore having previously been estimated by eye, an allowance for this is made; but, as usually done, this allowance and the other calculations are incorrect. It may therefore be useful here to put down, for the advantage of those who will adhere to this system rather than attempt a complete chemical determination of the arsenic, the true percentages of loss on roasting the three kinds of pyrites—copper, iron, and arsenical—or as they are termed in Cornwall, yellow ore, sulphur mundic, and white mundic.

Copper pyrites loses on roasting, ...	14 per cent.*
Iron pyrites loses on roasting, ...	33 "
Arsenical pyrites loses on roasting, ..	51 "

Also, by theory, a loss of 100 in the weight of arsenical pyrites implies the formation of 119 of arsenious acid or white arsenic.

If, therefore, for an example, an inspection shows the ore to contain, besides non-metallic substances, the three minerals about in the proportions 1, 2, and 4; then 14×1 (= 14), 33×2 (= 66) and 51×4 (= 204), or, centesimally, 4·9, 23·2, and 71·8, are the proportions of the loss on roasting which are due to the presence of those three substances respectively. Suppose, now, 100 grains of such a mixed ore had been assayed, and by roasting a loss of 40 grains had occurred, then 71·8 per cent. of that loss, or 28·7 grains, was due to arsenical pyrites. But since a loss of 100 in the weight of arsenical pyrites implies the formation of 119 of white arsenic, it follows that, in the case before us, something more than 34 per cent. of that product could be derived from the ore.

We now proceed to describe the metallurgical process. This consists of a roasting or calcination, followed by a resublimation or refining.

1. *Roasting or calcination.*—This is done in one of five different ways; that is to say, either (*a*) in a reverberatory furnace, (*b*) in a Brunton's calciner, (*c*) in an Oxland and Hocking's calciner, (*d*) in kilns, or (*e*) in a muffle-furnace.

(*a*). *Roasting in a Reverberatory Furnace.*—For this there are two kinds of furnace in use. One is a small reverberatory furnace, whose description in Pryce's "Mineralogia Cornubiensis" of last century holds good, with very little change, at the present time.† The flat bed is about 10 feet in length and 3 feet wide towards the fireplace, 5 or 6 feet at the belly, and 18 inches at the flue end, where there is an aperture with an iron door, through which the ore can be stirred by raking. This furnace is applied to the roasting of the tin ores after stamping, when

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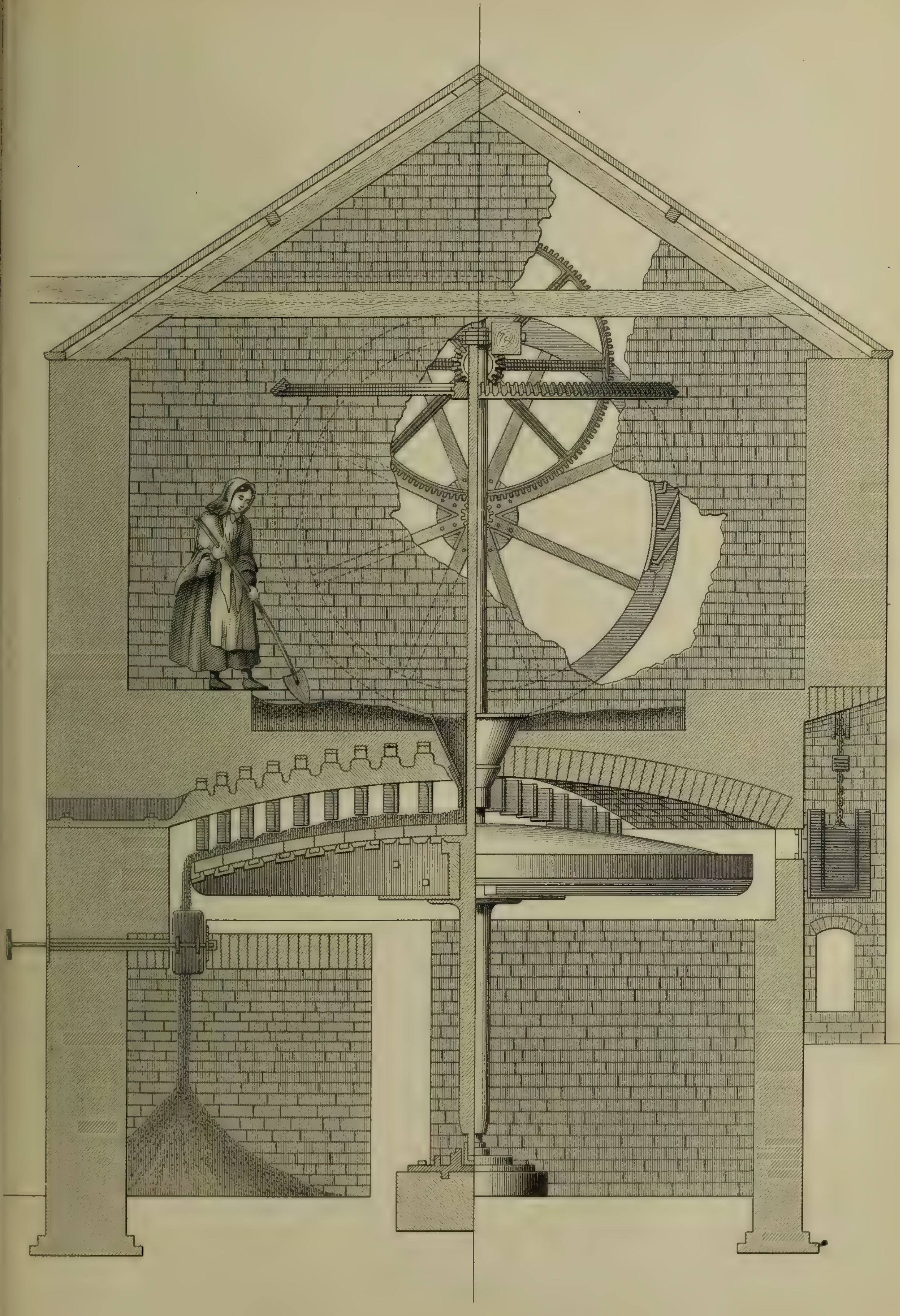
* These numbers are calculated on the supposition that all the copper will have been converted to protoxide, and all the iron to peroxide.

† The furnace, in its present form, is figured in The Proceedings of the Institute of Civil Engineers, vol. vii., Plate 6, figs. 21 and 22, in illustration of Mr. Henderson's paper on the Dressing of Tin and Copper Ores.

ARSENIC.

BRUNTON'S CALCINER.



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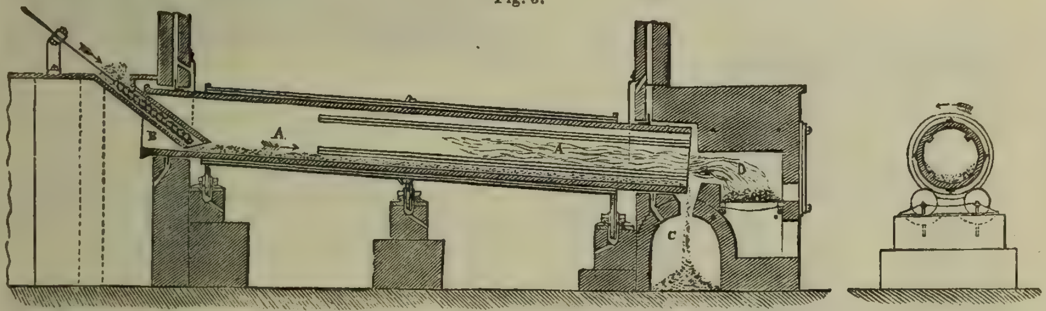
they contain pyrites of any sort. The ore is first dried on the top of the furnace, and then introduced to the quantity of about 8 cwts. and spread equally over the bed; after once heating to a dull red heat it has to be continually turned over with a rake, until all the sulphur and arsenic has been expelled (a process which takes about ten hours), after which the ore is drawn through an aperture in the bed, which is ordinarily closed by an iron plate, the arsenic meanwhile having been deposited in the form of arsenious acid in the flues or chambers, which will in due course be described.

The other form of reverberatory furnace is one that is coming increasingly into use, especially where the works are on a large scale. It is generally arranged so as to make a double furnace, or two furnaces put side by side and separated by a wall, while at the end their flues unite; each of them is nearly 30 feet long and 6 or 7 feet wide, with an *inclined bed* sloping gently from the flue towards the fireplace; the fireplace itself is narrow. A great expenditure of fuel is not required, if the ore has much pyrites of any sort, to raise it to the necessary steady, gentle, red heat—the sulphur and arsenic themselves burning keep up the heat; there are seven doors on each side of the double furnace. In the first instance the ore is spread over the bed (to a thickness of 5 or 6 inches) by being thrown in through these seven openings; afterwards it is supplied only through the top door, and the charge is then gradually, as calcination goes on, worked downwards by long levers with a narrow paddle-head. During the time taken by the passage of it along the whole length of the furnace the ore becomes well calcined, when it falls through a slit at the lower end, while other ore is being constantly supplied at the top, and there is a movement of the whole kept up at intervals by the men who *paddle* it down. The finely-stamped tin ore is not thus treated; such a furnace as this is intended for crushed ores containing arsenic, with either copper or perhaps some tin, for which the residue from this process may be afterwards stamped. Yet another form of furnace has been tried, but not with the best results; in this the flames are made to pass *beneath the bed* of the furnace (so as to heat the ore from below) before coming to the bridge, over which, passing, they play as usual on the upper surface of the charge.

Fig. 3.



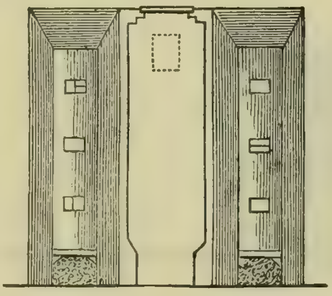
(*b*). *Brunton's Calciner.*—This machine will be understood from the section in Plate I. It may be described as a reverberatory furnace of which the bed revolves; there are, however, *two* fireplaces, the flames from each of which traverse half the circle, and unite at the flue opposite. The revolving bed (which has a diameter of about 8 feet) is of fire-bricks, resting on an iron table; it is higher in the centre than at the circumference; the ore (which for this calciner is the finely-stamped sort) is introduced in the centre through a hopper from a chamber above, where, over the furnace, it had been spread to dry. Fixed in the top of the furnace, and reaching down nearly to the bed, project numerous iron scrapers, shaped like the coulter of a plough, placed obliquely to the radii. On the ore being brought against these in the revolutions of the bed, it is turned over and turned outwards, so that gradually it finds its way down to the circumference, being roasted on the journey, when it falls into a chamber beneath. The bed is made to revolve by steam or water power at the rate of once in about a quarter of an hour; in the figure a water wheel to drive it is shown; the machine is almost self-acting. This calciner is now a good deal used in Cornwall.

(*c*) *Oxland and Hocking's Patent Calciner.*—(Fig. 3.) The principle of this is probably superior to that of the last, but both are liked in Cornwall, and each may be best suited for certain ores. The illustration (which is taken from the "Proceedings of the Institution of Mechanical Engineers," 1873) gives longitudinal and transverse sections. It should be premised that this machine also is intended only for finely-stamped ores. A wrought-iron cylinder, A A, of which the dimensions, as shown in the drawing, are 32 feet in length and 4 feet diameter, is lined with 4 inches of fire-brick, while four longitudinal ribs of fire-brick occur for part of the length. This cylinder is mounted in an inclined position, and made to revolve slowly by machinery (once in eight or ten minutes) upon three, or sometimes only two, pairs of friction wheels. A fire-place, D, is arranged at the lower end, of which the cylinder becomes the flue. The ore is introduced at the top either by an Archimedean screw, B, or from a hopper by hand; in the revolution of the tube it becomes lifted to a certain height, and then falls in such fashion that the particles become well exposed to the oxidizing influence of the flame and air that pass through. In each turn it comes a little lower down the tube, and ultimately reaches the lower end, whence it falls into a chamber, C, in a calcined state, the sulphur and arsenic having been driven off to the flue chambers.

In this calciner as much as 6 or 7 tons of ore can be treated in twenty-four hours. For such a size as we have spoken of the cylinder is not uncommonly made of an old tube of a Cornish boiler; larger ones, however, have been tried, and have done well. The boiler-shell itself may be used for the purpose, the diameter of which would be 5 feet 6 inches or so; in this case the fire-brick lining could be 9 inches thick, so as to leave 4 feet clear inside. It has been found that it is not necessary (at all events with the large ones) to give any inclination to the cylinder; the slope which the ore acquires on being fed from the top is sufficient to carry it down the length of the tube in its revolutions.

(*d*). *Calcining in Kilns.*—For certain kinds of ore this is probably the cheapest method of any. If the ore can be mixed so as to contain something like 20 per cent. of pyrites, the only expenditure of fuel will be at first lighting. The kilns are of the simplest construction. Fig. 4 shows three side by side, of which the middle one is seen in section. The diameter is 3 feet, the height 10 feet. The top is covered with an iron plate, which is removed when the ore is to be introduced, while the flues (one of which is represented by dotted lines) lead away from just beneath it and then unite. At first starting the kiln is filled nearly to the top with rubbish; above is put ore with a little fuel; as this gets hot and begins to burn of itself, some of the rubbish is raked out from below, while more ore (without fuel) is added above. In the course of time all the rubbish will have been got rid of, and the kiln will be filled with a burning mass of ore. Some is then raked from the bottom five or six times in twenty-four hours, and a corresponding amount of ore is put in at top; in this way from 1 ton to 1¼ ton is done per day per kiln, the work being continuously kept up. There will be observed in the kilns three holes (closed up by bricks) at different levels; these are to give access to the ore in case poking should be required to make it descend. With the poorer ores a proportion of fuel may be mixed to produce the necessary heat.

Fig. 4.



For this method of roasting the ore may be crushed so as to pass through 1¾-inch meshes. We would point out that, for ores containing tin and a proper proportion of pyrites, it might be advisable to roast them thus and afterwards send them to the stamps, for which they would have been well prepared by the calcination.

(*e*). *Roasting in a Muffle Furnace.*—This is practised at Altenberg and at Reichenstein in Silesia. Figs. 5 and 6 are explanatory of the furnace; the first shows a longitudinal and the second a transverse section; the same characters in each indicate the same parts. The muffle of the furnace, where the ore is deposited for roasting, is indicated by *a*; *b* is a door in the front of the muffle, through which the workman introduces his slicer to work the charge and draw out the exhausted material; *c c c* are the flues round the muffle, where the smoke and flame from the fire are carried forward to the main flue, *e*, leading to the chimney. From the muffle two channels, *f f*, lead to the first chamber, B, appropriated for the condensation of the acid, the further course of which will be spoken of below. For this process the ore is reduced to a moderate size by crushing, in which state it is called *schliech*. About 10 cwts. of the *schliech* forms the charge, which is introduced through the opening, *d*, and spread upon the inclined bed of the furnace to the depth of from 2 to 4 inches; this is raised to a gentle red heat, which is afterwards slightly lowered, and then maintained equably, the ore being at the same time frequently stirred. The door, *b*, is kept open, that the air entering may oxidize the sulphur and arsenic. In about twelve hours this oxidation is effected; the exhausted ore is then raked out and another charge introduced as before.

Fig. 5.

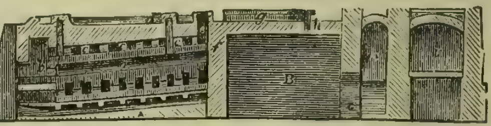
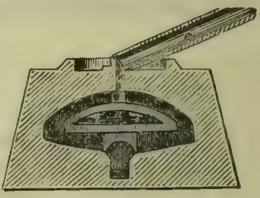


Fig. 6.



The Flues or Chambers.—By whichever of these processes (except it be the last mentioned) the ore may be roasted, the arsenious acid that may be volatilized is intercepted in chambers constructed in the course of the flue, through which all the products of combustion pass between the furnace and the stack. The best arrangement of flue-chambers is that shown in the accompanying diagrams (Figs. 7 and 8). There is a long line of chambers so arranged that the smoke shall zig-zag through them; each chamber is 3 feet wide, about 15 feet long, and 6 feet 6 inches high to the top of the arch. To every two chambers is a low doorway from outside, which is closed by an iron door luted on to the brick. The smoke from the calciner must be led through a great length of such chambers, for the double purpose of saving all that can be got of the arsenious acid, and of preventing the harm to the vegetation that would follow from the escape of any great quantity of it. The white arsenic that collects is cleared from the chambers about once a fortnight; it is found spread or heaped on the floor, and attached to the walls, partly in a pulverulent, and partly in a crystalline form, but discoloured by coal soot. To clear out the chambers the furnaces must be stopped, unless (as is done in large establishments) there is arranged a double set of chambers, the two divisions of which diverge from the flue that collects the products of the furnaces, and converge again towards the stack. The object of this is to have one set of chambers free for emptying, while the other set is at work—dampers at the point of divergence regulating the direction of the current of the gases. Sometimes a separate range of chambers intervenes nearer the stack which shall take longer in filling, receiving but the last of the arsenical smoke, and needs to be cleared out but twice a year or so.

Fig. 7.

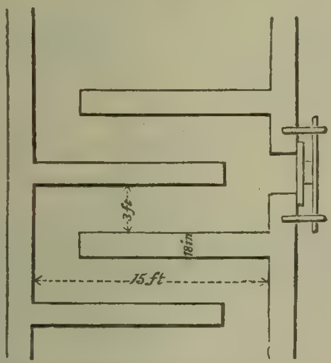
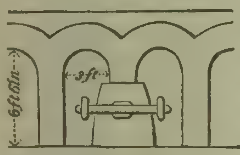


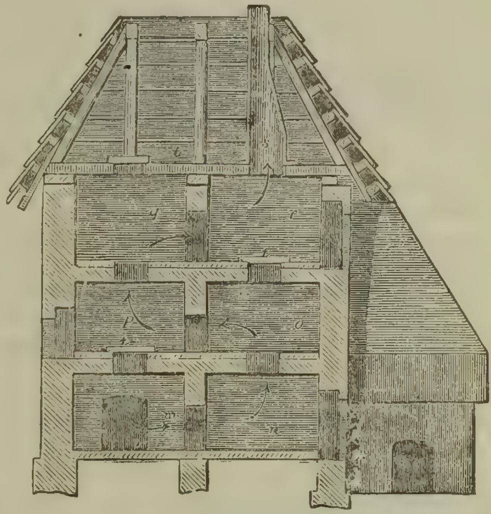
Fig. 8.



This product of the calcination is called arsenical soot; as before said, it is impure, being mixed with carbon, &c., from the furnaces, and probably containing some sulphur compounds. Some of it, indeed, may be white, but when all is mixed up together it is of a blackish grey colour. From many mines this is sold as it is to works where the plant is necessary for the next, the refining, process.

In Silesia, where the muffle furnace is used for the calcination, the condensing chambers are in a lofty building called the *poison-tower*, of which a section is shown in Fig. 9. The leading passages from the furnace, as shown in Fig. 5, communicate with the lowest room of the poison-tower. The vapours from the muffle (but not the gases from the fireplace) thus entering are made to traverse all the chambers it contains (following the direction of the arrows), and what is uncondensed (chiefly sulphurous acid) escapes at the top by the chimney, *s*. In the flues and first chambers of the tower the purest arsenic is to be found, that which is deposited in the upper ones being impregnated with sulphur. At the termination of the working of each charge, the covers, *t t*, are taken away for the purpose of collecting the whole of the condensed arsenious acid into the lower chamber, which is emptied only about once in every two months, and contains at that period about 25 tons of the impure compound. This product must be purer than the arsenical soot of the English process, not being mixed with particles of the fuel. It has not to undergo the process that we next describe, but goes at once for the making of arsenic glass.

Fig. 9.



2. *Refining or Resublimation.* — This is nothing more than a repetition of one form of the previous process. A long reverberatory furnace with sloping bed is used; this is not, however, quite so long as that intended for the ore, but it may be 18 feet in length, and 6 or 7 in width, with four side doors through which to work the charge. The arsenical soot is supplied at the upper end, and paddled down and spread pretty equable over the bed. As it volatilizes, more is added, and the action is kept up continuously for long; only when extraneous matters have so accumulated on the bed as to make it foul, is the firing stopped. It should be noted that, since in this last process it is very necessary to keep the volatilized product clean, and free from anything of a reducing power, it will not do to burn ordinary coal; a mixture of culm (anthracite) and coke is found to be best. The product of this second calcination (of which the chemical result is a complete

oxidation of all that was contained in the soot, and subsequent separation of the condensable oxide of arsenic) is collected in another set of chambers exactly like those above figured; and there may be the same looping of two lines of chambers which shall alternately be cleared out.

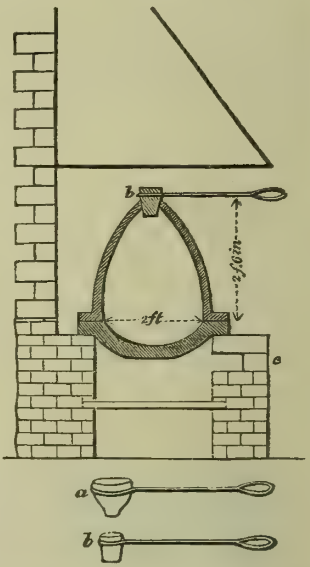
The arsenious acid as thus obtained is a beautifully white minutely-crystalline substance; it hangs on the walls and roofs of the chambers, and accumulates on the floor in glittering masses. After being collected it has to be prepared for the market by grinding in a mill just like a flour mill, from which, indeed, it comes out exactly like flour to look at. From the mill it goes to a hopper with a leather hose attached, which hose has at its end a collar and screw, by which it is fastened to the keg in which the white arsenic is to be packed; by a series of light blows on the cask the material is shaken down hard till the keg is thoroughly full, when it will hold 3 cwts. or $3\frac{1}{2}$ cwts.; it is then ready for carriage.

In dealing in all these ways with such a poisonous substance as arsenious acid, certain precautions are necessary. The way in which it affects the men at the furnaces, &c., is in producing sores wherever it may collect and be allowed to stay. The men sometimes smear their faces with fuller's earth as a protection; without that the bad effects may be kept off by thorough cleanliness, by careful washing when the day's work is over.

With regard to the harm that may be done to the neighbourhood by the escape of arsenious acid from the stack, this has probably in many cases been confounded with that which arises from the sulphurous acid gas that spreads from the same stack; the chambers should be of length sufficient to intercept nearly all the arsenic.

Manufacture of White Arsenic Glass.—White arsenic glass is arsenious acid in an amorphous vitreous form. At the ordinary pressure of the atmosphere, arsenious acid volatilizes from the solid form, and solidifies at once from its vapour at the temperature of 185° C. (365° Fahr.); but it would seem that, under a slightly increased pressure, the vapour on condensing becomes for a moment a liquid, or we may say that, on solidifying from the gaseous state, it *passes through the liquid stage*, and hence the product is vitreous. The increased pressure causes the fusing and volatilizing temperatures to be distinct. Such, at all events, is our explanation of the result of the process now to be described. It consists of a re-sublimation of the white arsenic under new conditions. There are two somewhat different ways of effecting this. We will first describe the one followed at Swansea, in Wales. Fig. 10 represents the apparatus there employed. It consists of a cast-iron pan, 2 ft. across, surmounted by a bell of the same material, 2 ft. 6 in. high. The pan is fixed permanently over a fire, the bell is removable. The bell being adjusted as in the figure, and the pan being heated to a cherry-red heat, a charge of about $\frac{1}{4}$ cwt. of refined white arsensic is introduced through a hole in the top of the bell by the funnel marked *a*; the hole is then stopped by the plug *b*. The arsenious acid soon sublimes, and, on account of the heat of the vapour *under a certain amount of pressure*, it is deposited on the inside of the iron bell in an amorphous state—as a transparent glass, that which is an article of commerce under the name of white arsenic glass. As soon as the first charge has been worked off (and one can ascertain the state of it by introducing an iron rod through the plug-hole), another is introduced. The plug also may be from time to time removed to relieve the pressure if it should be too great; or if the fire becomes too hot, the brick *c* may be removed. For the first charge to be thus sublimed and condensed about two hours is required; the time necessary increases to three or four hours as the bell acquires a thicker cake. At the end of twenty-four hours the bell, with its contents, are removed, and a cold one takes its place; the arsenic glass formed inside the bell is about 1 inch thick; it is broken out and put in casks for transportation.

Fig. 10.

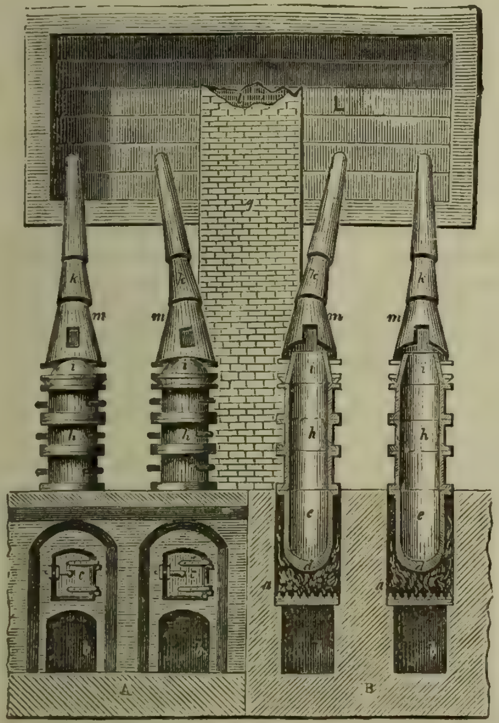


The method followed at Reichenstein, in Silesia, is somewhat different, though proceeding on the same principle. There the product of the roasting in the muffle furnace above described is submitted to treatment, which will be understood from the subjoined drawing, Fig. 11.

The part A is a front view, while B is a section of the apparatus employed. *a*, *a*, are the fire-grates, *b*, *b*, the ash-pits, *c*, *c*, the doors; the smoke from the various fire-places is carried off by the chimney, *g*; *e*, *e*, are subliming-pots of cast iron, into each of which a weight of about $3\frac{1}{2}$ cwts. of the flour of arsenic is introduced; they are surmounted by the iron drums, *h*, *h*, and by the caps, *i*, *i*, which in their turn are covered by pipes, *k*, *k*, the narrow ends of which enter the condensing chamber, L. The pots being charged, the cylinders, *h*, *h*, are placed upon them by the aid of the handles with which they are furnished, and the joints being well luted with a composition of loam, hair, and blood, the caps, *i*, *i*, and the pipes, *k*, *k*, are adjusted, and, lastly, the fire is lighted. A very gentle heat is applied for about half an hour, after that time the heat is somewhat increased. If the heat be too feeble, the sublimate produced is similar to what was put in; if it be too strong, much is driven into the pipes and the condenser. The result sought for is to obtain a vitreous homogenous mass in the cylinders. This should be produced at the end of twelve hours; the fire is allowed to go out, the cylinders are lifted off, and the arsenious acid glass is detached from them. Sometimes this acid is interspersed with dark spots of metallic arsenic; whenever this happens, either the whole compound must be sublimed anew, or those parts picked out if such an operation is practicable. By this process good crude arsenious acid yields from three-fourths to seven-eighths of its weight of the glass.

It is clear that in this process there is the same condition—of somewhat increased pressure—which, in the previously described one, was pointed out as the cause of the vitreous state of the product.

Fig. 11.



Arsenious acid is used for the following purposes:—For destroying the colour communicated by protoxide of iron, and for other purposes in glass-making; in dyeing and calico printing; in the preparation of various arsenical compounds which are used as pigments; in the manufacture of aniline dyes; and by naturalists (in the form of arsenical soap) to preserve organic specimens from putrefaction and from the ravages of insects. In medicine it is used only to a limited extent.

Manufacture of Realgar.—Realgar (the composition of which is AsS_2) is made artificially by distilling a mixture of arsenical ores (ores containing arsenical and iron pyrites) with sulphur, or the sulphide of arsenic precipitated in purifying sulphuric acid. The materials should be mixed so as to contain 15 per cent. of arsenic and 26 to 28 per cent. of sulphur, since much of the sulphur will be driven off in the process. A furnace and gallery are erected, in which a number of earthen retorts are placed, as seen in the annexed cuts, Figs. 12 and 13.

The retorts (which are of earthenware) are charged every twelve hours with 60 lbs. of ore to each; they are connected with similar vessels for receivers, which are permeated by a number of small holes to allow the gases to pass off. The charge fills the retorts to about two-thirds of their capacity. They are then gradually heated to redness, and kept in that state for eight, ten, or twelve hours, when the furnace is allowed to cool; the receivers are taken off, and the crude realgar taken from them for remelting. The crude product is almost sure to have either too much arsenic or too much sulphur; it is preferred that it should be a compact dark substance, rich in arsenic, and still requiring sulphur, rather than that it should be a friable light red substance requiring arsenic. The remelting is done quickly in cast-iron pans; the mass is stirred up and the slag is removed; then sulphur or arsenic (as may be required according to its colour), or else other realgar having opposite qualities, is added, and again there is a stirring and a removal of slag. When the glass flows off thin from the iron rod, and when on cooling it shows the proper colour and compactness, then the liquid mass is let off into conical moulds of sheet iron, from which, when cold, the glass is turned out in lumps and broken up. The average composition of the product is—

Fig. 12.

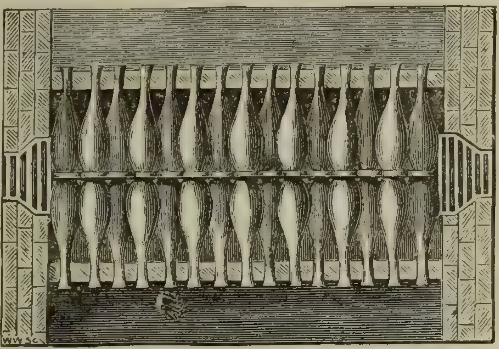
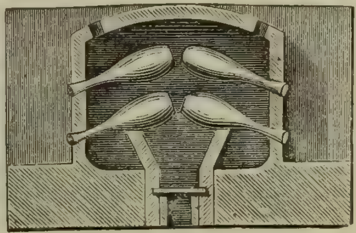


Fig. 13.



Arsenic,	75 per cent.
Sulphur,	25 per cent.

Manufacture of Fly Poison (Fliegenstein).—At Reichenstein, at Rebas in Spain, and at Freiberg, the ores richest in arsenic are usually sublimed for fly powder. These rich ores, if used for realgar, would stop the neck of the receiver with metallic arsenic. The process is carried on in a mode similar to that last described, but between the retort and the receiver, or rather partly in each, there is a piece of sheet iron, spirally rolled and coated with clay; in the interspaces of this the greater part of the arsenical vapour (fly poison) is condensed. The receivers have a little door of sheet iron, which remains closed till towards the end of the operation, when it will be necessary to observe the interior. The retorts themselves are glazed inside with a mixture of clay, blood, calves' hair, iron scale, and alum.

MANUFACTURE OF ORPIMENT.—The composition of orpiment is theoretically As_2S_3, but, as will be seen, the commercial product differs from this. It is a substance of a beautiful lemon or orange-yellow colour. It may be made by adding sulphur to realgar, but it is more commonly produced by fusing a mixture of arsenious acid and sulphur in the same kind of cast-iron pots as are used in making the white arsenic glass; it must be done at a temperature when the sublimate will just melt on the rings which surmount the pots. The proportion of sulphur used, as well as the proportion found in the product, vary much; perhaps the most beautiful colours are produced when from one-third to one-fifth of the mixture put into the pots is sulphur; but for the lighter kinds there is a much smaller proportion of sulphur. The result is probably a mechanical mixture of the sulphide with the oxide of arsenic.

The formula of orpiment is As_2S_3; it is the trisulphide of arsenic. Realgar is the disulphide (As_2S_2).

Orpiment is oxidized by nitric and nitro-hydrochloric acids, and dissolved by alkalies and alkaline carbonates; an arsenite together with sulphide of the alkaline metal being formed. Carbonic acid is expelled when a carbonate is used. Heated in close vessels, orpiment fuses and sublimes; in air, sulphurous acid is evolved, and arsenious oxide produced.

This arsenic compound is still used as a pigment, and is occasionally employed in dyeing to reduce indigo, which is dissolved by the potassium hydrate used at the same time. Orpiment was once used to dye silks, by dissolving it in ammonia, and passing the weft through the solution thus produced. On hanging the cloth up in the stove-room, the volatile ammonia was expelled, and the colour remained fixed upon the cloth. These compounds are highly poisonous, and should be used with the greatest care.

Furriers and tanners make an aqueous paste with 9 parts of orpiment and 1 of quicklime, which they term "rusma." This paste is applied in dressing skins to remove the hair, and as a toilet preparation to remove superfluous hairs; but its use for the latter purpose is attended with great danger. It is now to a great extent replaced in tanning by the calcium sulphide solution obtained by dissolving the spent lime of gasworks.

In pyrotechny, orpiment is used as an ingredient of white fire.

ARSENITES.—Arsenious acid unites with all the mineral bases in various proportions, and forms with them definite compounds, which, however, are for the most part unstable and of little utility in a manufacturing or artistic sense; moreover, though the result of chemical research, they have been but little examined. Those to which the most interest is attached are, potassium arsenite, and the compounds known as *Scheele's green* and *Schweinfurth green.*

Arsenites give a light green precipitate with copper salts, and a light yellow precipitate with silver nitrate. All arsenites yield a precipitate with sulphuretted hydrogen when they are dissolved in hydrochloric acid. The arsenites of the alkali and alkaline earth metals are decomposed by heat into metallic arsenic and a salt of arsenic acid, thus:—

$$\begin{array}{ccccc} \text{Arsenious oxide.} & & \text{Arsenic oxide.} & & \text{Arsenic.} \\ 5(As_2O_3) & = & 3(As_2O_5) & + & 4As. \end{array}$$

POTASSIUM ARSENITE, an acid salt ($K_2O,2As_2O_3$), is formed by dissolving arsenious acid in a solution of caustic or carbonated alkali, and evaporating the solution; or by decomposing barium arsenite by potassium sulphate; double decomposition takes place.

From this body neutral or monopotassic arsenite is obtained by boiling with potassium carbonate, and washing the residual compound with alcohol. Its formula is K_2O,As_2O_3.

ARSENITE OF COPPER $(Cu_2O)_2As_2O_3$ or $Cu_3(AsO_3)_2$, *Scheele's Green.*—This compound derives its name from SCHEELE, its discoverer, who gives the following direction for preparing it:—Dissolve 2 pounds of sulphate of copper in 3 gallons of warm water; in another vessel make a solution of 2 pounds of pure potassa and 11 ounces of arsenious acid in 1 gallon of water; filter both through a cloth, and while warm, mix them portionwise, keeping the menstruum briskly agitated at each addition. As soon as the precipitate settles to the bottom, the clear liquid is to be decanted or siphoned off, and the green powder treated with a gallon or more of hot water, and agitated. Next it is to be thrown on a filter, again washed once or twice with water, and finally dried at a gentle heat.

Another process followed, is to dissolve 2 parts of sulphate of copper in 44 of hot water, and to add to this solution another composed of 2 parts of carbonate of potassa, 1 of arsenious acid, and 44 of water. The green powder which is thus produced is washed well with water, and dried at 212° Fahr.

It is likewise formed when a salt of copper is precipitated with potassium arsenite, or with arsenious acid, and a sufficient quantity of ammonia to neutralize the acid present.

SCHEELE'S green dissolves in an excess of ammonia, forming a colourless solution of arsenic acid and cuprous oxide.

There are also two hydrated salts: $CuH_4(AsO_3)_2$, and CuH,AsO_3.

ACETO-ARSENITE OF COPPER. *Schweinfurth Green, Imperial Green, Emerald Green* $(CuAs_2O_4)_3Cu(C_2H_3O_2)_2$.—This pigment was first made in 1814, at the locality whence it takes its name. It is prepared by adding a solution of arsenious acid to verdigris.

In the cold, the change produced is different from that which subsequently results; a precipitate forms, which, instead of being of the rich colour of the compound, has an olive-green tint. On leaving the mixture for a long time to react, or by boiling it, a change occurs, and the olive-coloured precipitate becomes of a beautiful brilliant green hue. On the large scale it is manufactured thus: 10 parts of verdigris are diffused through sufficient water to form a thin paste, which is then passed through a sieve, after which 8 or 9 parts of finely-powdered arsenious acid are dissolved in 100 of boiling water, and the solution added while at the point of ebullition to the infusion of the verdigris in water in successive portions, care being taken to keep the mixture well stirred at each addition; and lastly, the whole is to be boiled for a few minutes, upon which the full tone of colour is developed. If cold water be poured into the hot solution without boiling, the peculiar green does not appear for some time; but a crystalline compound possessing a still richer hue is in this way produced, than by the foregoing method. In this country it is commonly sold as Emerald Green.

Another method is the following:—50 pounds of sulphate of copper and 10 of lime are dissolved in 20 gallons of ordinary vinegar, and a boiling hot solution of 50 pounds of arsenious oxide in water quickly stirred into it; the precipitate is dried and reduced to powder. In this process the precautions required to be taken in the preceding case are needful.

Both Scheele's Green and Schweinfurth Green are exceedingly poisonous, and should be used with great caution.

ARSENIC ACID.—*Arsenic oxide*, *pentoxide of arsenic*; *acide arsenique*, French; *arsensäure*, German; *acidum arsenicum*, Latin. Formula, As_2O_5.—This body was discovered by SCHEELE, who produced it by dissolving arsenious oxide (As_2O_3) in aqua regia—nitro-hydrochloric acid—and distilling the mixture to dryness in a retort. The residue is solid arsenic oxide. An easier method, however, of procuring this acid, is to dissolve arsenic in nitric acid, and to evaporate the solution to dryness: 4 parts of arsenious oxide are added very gradually to 3 parts of fuming nitric acid; the mixture becomes very hot, and in about twenty-four hours an oily liquid is produced, which consists mainly of arsenic acid; any unoxidized arsenious oxide is converted into arsenic oxide by the addition of a little more nitric acid.

Arsenic oxide is likewise produced by acting on arsenious oxide with any powerful oxidizing agent.

Arsenic oxide is deliquescent and crystallizable; it fuses at an incipient red heat, concreting on cooling into a vitreous mass. At a higher temperature it is decomposed, oxygen is evolved, and arsenious oxide sublimes. Its specific gravity is 3·7. To dissolve it, 6 parts of cold and 2 parts of boiling water are required. Its solution, which reddens vegetable blues, has an acid and metallic taste, and is a virulent poison, though less so than arsenious acid. The taste of the arsenic oxide is not very remarkable when dry, but when moistened it becomes exceedingly acrid. Arsenious acid gives a white precipitate with lime-water, a peculiar reddish-brown with nitrate of silver, and gradually yields a yellow deposit of trisulphide of arsenic when its solution is subjected to the action of a stream of sulphuretted hydrogen gas. Its precipitate with ammonia-sulphate of copper is pale greenish blue.

Arsenic acid forms three hydrates:—

Monohydrate,............... $As_2O_5H_2O = HAsO_3$.
Dihydrate,.. .... $As_2O_5(H_2O)_2 = H_4As_2O_7$.
Trihydrate,................ $As_2O_5(H_2O)_3 = H_3AsO_4$.

Arsenic acid at high temperatures displaces all the more volatile acids from their salts. It is tribasic, but either one or two atoms of the metal may be replaced by hydrogen. Salts containing three and two atoms of metal are alkaline or neutral. Monometallic salts have an acid reaction. They may be represented thus:—

Monammonic or acid arsenate of ammonium,...$(NH_4)H_2AsO_4$.
Diammonic or neutral arsenate of ammonium,.$(NH_4)_2HAsO_4$.
Triammonic or basic arsenate of ammonium,....$(NH_4)_3AsO_4$.

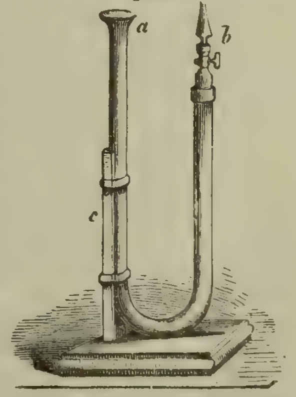
ARSENIC TRIHYDRIDE.—*Arsenious hydride*, *arsenetted hydrogen*, *arsine*, AsH_3.—Arsenic forms two compounds with hydrogen, the gaseous trihydride (AsH_3) and the dihydride (AsH_2), which is a brown powder. The trihydride only will be described.

Arsenic trihydride is a colourless gas, which can be liquefied by combined pressure and withdrawal of heat, but cannot be solidified. Its composition is analogous to that of ammonia. Its odour is particularly disgusting, and when breathed in even a very dilute state it produces nausea and giddiness. Animals immersed in it are at once killed. One volume of this gas contains 1·5 volumes of hydrogen and ·25 of arsenic vapour. Its vapour density is 2·695, air being unity.

DETECTION OF ARSENIC.—Arsenetted hydrogen is formed whenever hydrogen is evolved from a solution containing a salt of arsenious acid. Great care must be taken to avoid inhaling the gas, since fatal accidents have occurred through want of caution.

The combination of the two elements may always be effected by bringing together arsenious acid, or any arsenical compound, and zinc, water, and sulphuric or hydrochloric acid. This property was first taken advantage of as a test for the metal by MARSH of Woolwich. The apparatus he employed is shown in Fig. 14. The stopcock, *b*, being removed, a few fragments of pure zinc are introduced into the bend of the tube, and pure dilute sulphuric acid then added; the jet, *b*, is fixed on, *a* is closed with the

Fig. 14.

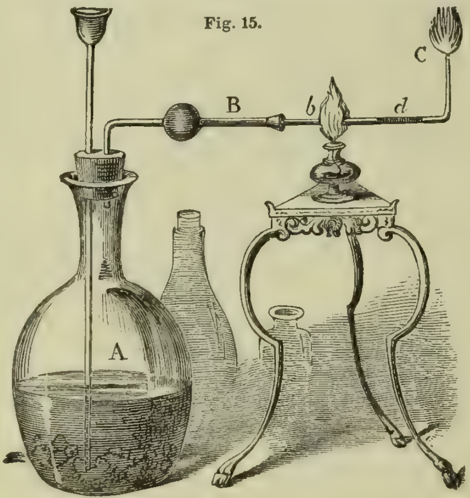


thumb, and the gas evolved having been proved to be free from arsenic, by no deposit being formed when burned against a porcelain plate, the suspected liquid is then examined in a similar manner.

It deserves to be remarked, however, that pure zinc, especially when in large pieces, frequently dissolves so slowly in dilute sulphuric acid that it is impossible to obtain a steady hydrogen flame. The addition of a drop of bichloride of platinum, or of a small quantity of platinum black, will remedy this difficulty. If the fluid to be tested contains any considerable quantity of arsenic acid, this addition is sufficient to produce a violent reaction of the acid on the zinc.

All the apparatus based on the above principle are called after Marsh. Fig. 15 is a convenient form. The materials for generating the hydrogen are introduced into the evolution flask, A, and the gas, discharged through a tube, B, filled with dry cotton wool, is (sufficient time having been allowed to discharge the atmospheric air from the apparatus) inflamed at the point of the bent tube, C, and a porcelain plate depressed on the flame. If, after burning for some time, no incrustation or blackening appears on the plate, it is a sign that the materials are free from arsenic; additional assurance is, however, obtained by heating a portion of the horizontal tube to redness at *b*, by means of a spirit lamp; no incrustation should be observed in the tubes. The liquid to be tested for arsenic is now introduced into the evolution flask through the funnel tube; and if it contain any traces of the metal the flame of the hydrogen will acquire a bluish-white colour, from the reduction and separation of the arsenic, and fumes of arsenious acid will make their appearance. On bringing the porcelain plate in contact with the flame, brown arsenic spots, having a shining metallic appearance, will be obtained.

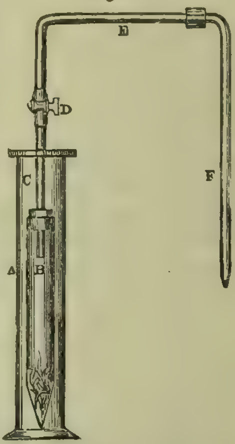
Fig. 15.



On directing the flame of the spirit lamp to the horizontal part of the tube, a beautiful incrustation of metallic arsenic, *d*, will be formed in the cold part; and on cutting off the end near the deposit, and applying heat, the arsenic is converted into arsenious acid, which may be dissolved in hot water, and tested by nitrate of silver or sulphate of copper.

The following, Fig. 16, is Dr. Ure's modification of Marsh's apparatus:—A is a narrow glass cylinder, open at the top, about 10 inches high, and $1\frac{1}{2}$ inch in diameter inside. B is a glass tube about 1 inch in diameter outside, drawn to a point at the bottom, and closed with a cork at the top. Through the centre of this cork the small tube, C, passes down air-tight, and is furnished at the top with a stopcock, into which the small bent hard glass tube (free from lead), E, is cemented. The bent tube, E, is joined to the end of F by a perforated cork.

Fig. 16.



This apparatus is to be used thus:—Introduce a few oblong slips of zinc, free from arsenic, into B, and then insert its cork with the attached tubes. Having opened the stopcock, pour into the tube, A, as much of the suspected liquid, acidulated with dilute sulphuric acid, as will rise to the top of the cork after B is full, and immediately shut the stopcock. The generated hydrogen will force down the liquid out of the lower orifice of B into A, and raise it above the level of the cork. The extremity of the tube, F, being dipped beneath the surface of a weak solution of nitrate of silver, and a spirit flame being placed a little to the left of the letter E, the stopcock is then to be slightly opened, so that the gas which now fills the tube, B, may escape so slowly as to pass off in separate small bubbles through the silver solution. By this means the whole of the arsenic contained in the trihydride of arsenic will be deposited either in the metallic state upon the inside of the tube, E, or with the silver will pass into the characteristic black powder. The first charge of gas in B being expended, the stopcock is to be shut till the liquid is again expelled from it by a fresh disengagement of hydrogen.

The ring of metallic arsenic deposited beyond E may be chased onwards, by placing a second flame under it, which forms it into an oblong, brilliant, steel-like mirror.

It is evident that, by the careful use of this apparatus, the whole of the arsenic in any poisonous liquid may be collected, weighed, and subjected to every kind of chemical verification. By means of the perforated cork, the tube, F, may readily be turned about, and its taper point raised into such a position as that, when the hydrogen issuing from it is kindled, the flame may be made to play upon a surface of glass or porcelain, in order to form the arsenical mirror.

Reinsch's Test.—A grey metallic film is produced when a perfectly clean strip of copper is immersed in a hot solution of arsenious acid, or an arsenite mixed with hydrochloric acid. On washing the free acid from the coated copper, and then heating it in a solution of ammonia, the film peels off and separates, forming minute spangles of arsenide of copper, Cu_6As. It must, however, be borne in mind that this test is not by itself conclusive, since antimony and some other metals are likewise deposited upon copper under similar circumstances.

Bloxam's Test.—The occasional presence of arsenic in the sulphuric acid, and of both arsenic and antimony in the zinc, is, in C. L. BLOXAM'S opinion, a strong objection to the use of MARSH'S test; another objection being that the liquid which has been examined by this method for arsenic and antimony cannot be examined for other metals, on account of the presence of so large a quantity of sulphate of zinc, a consideration of much importance in cases where the quantity of the suspected matter is small.

The detection of poisonous metals by the decomposing action of the voltaic current is free from these drawbacks, and such minute quantities of poisonous metals may be detected by BLOXAM'S method of testing, that it may safely be relied on in most cases of chemico-legal investigation.

The apparatus most suitable for the detection of arsenic by electrolysis, consists of a two-ounce narrow-necked bottle, the bottom of which has been cut off, and replaced by a piece of vegetable parchment tightly stretched over it, and secured by a ligature of thin platinum wire (vulcanized caoutchouc is speedily corroded). The bottle is furnished with a cork carrying a small tube bent at right angles, and connected with a drawn-out reduction tube by a caoutchouc tube, and a funnel tube for pouring in the acid and solution to be tested; through this cork also passes a platinum wire bent into a hook inside the bottle, for suspending the negative plate. The bottle is placed in a glass of such a size as to leave a small interval between the two, the whole apparatus being then placed in a large vessel of cold water. An ounce of dilute sulphuric acid is next introduced into the bottle and its outer glass shell, so as to fill both to the same level; the positive plate being immersed in the acid contained in the outer space.

The current of a voltaic battery (six Grove's cells) is then passed through the arrangement, and when the bottle is filled with hydrogen, the shoulder of the reduction tube is heated to redness for fifteen minutes to ascertain the purity of the sulphuric acid, after which the liquid to be tested is introduced into the bottle by means of a pipette; a drachm of alcohol is afterwards added to prevent potting; the cork is removed for as short a time as possible: $\frac{1}{1000}$ of a grain of arsenic diffused through a large bulk of liquid can be detected by this apparatus.

QUANTITATIVE ESTIMATION.—Arsenic is quantitatively determined in various ways.

As Sulphide.—In general cases, when the liquor contains substances not precipitated by sulphuretted hydrogen, the arsenical solution may be acidified with hydrochloric acid and determined by passing through it a current of sulphide of hydrogen. If the liquor be dilute, a precipitate of trisulphide of arsenic is produced, the composition of which corresponds to that of arsenious oxide. The stream of sulphuretted hydrogen is continued until the liquor is completely saturated, the whole is then left at rest in a moderately warm place until the odour of the gas has vanished, when the traces of trisulphide of arsenic held in solution by the excess of the gas are thrown down. A small portion of the precipitate commonly adheres so strongly to the side of the vessel, and of the glass tube which dips in the liquor, that it cannot be removed by mechanical means; this is very easily dissolved by a few drops of ammonia, and the solution added to the acid liquor, which reprecipitates the small quantity of dissolved trisulphide of arsenic. If the liquor contains any oxide of cobalt which is to be subsequently determined, a solution of carbonate of soda must be employed instead of ammonia, because oxide of cobalt cannot be completely precipitated by potassium hydrate from a solution which contains ammonia.

The trisulphide of arsenic, which is of course mixed with some free sulphur, is collected upon a tared filter, washed, dried at a very gentle heat, and then weighed. All that can be shaken from the filter is then put into a glass vessel, and the filter is again weighed in order to know the amount of substance submitted to experiment. Aqua regia or hydrochloric acid and potassium chlorate is then added to it, and the whole left to digest for some time. The action of the acid upon trisulphide of arsenic in fine powder is very energetic, even in the cold, owing to which the oxidation must be performed in capacious vessels. The arsenic is oxidized into arsenic oxide, and a portion of the free sulphur is converted into sulphuric acid. In order to convert the whole of the sulphur into sulphuric acid, the digestion in aqua regia, which would need to be frequently renewed, would require too long a time. On this account, as soon as the sulphur is agglomerated into small lumps, it is collected upon a counterpoised dry filter, washed, dried most carefully, and weighed. A solution of chloride of barium is added to the filtered liquor, and the sulphate of barium determined with the usual precautions; from its weight, that of the sulphur in solution is calculated. The sulphate of barium is very difficult to wash, on account of the presence of nitric acid in the solution. The collective quantities of sulphur indicate the amount which existed in the sulphide of arsenic subjected to analysis; the loss indicates the loss of the arsenic, from which the proportion of the arsenious acid is calculated. It is necessary to take care, in this operation, to collect the undissolved sulphur only after a prolonged digestion in aqua regia.

Or, the dried mixture of trisulphide and sulphur may be decomposed by ignition in an atmosphere of hydrogen, when the sulphur will be removed as sulphuretted hydrogen, and a residue of metallic arsenic will remain behind.

Instead of the preceding method the following may be adopted:—The acid liquor is supersaturated with ammonia, and a quantity of ammonium sulphide is added which produces a precipitate of tri- and pentasulphide of arsenic, which dissolves easily and completely in the excess of sulphide of ammonium.

If the solution is very concentrated, it should be diluted with a large quantity of water, and hydrochloric acid carefully added, till it gives a feeble acid reaction with litmus paper. Trisulphide of arsenic is thereby precipitated, with disengagement of sulphuretted hydrogen. The liquor is digested at a gentle heat, until the odour of the sulphide of hydrogen has disappeared, and the arsenic trisulphide produced is separated by filtering.

It is absolutely necessary to proceed with this sulphide as in the former case, because it is mixed with much sulphur from the decomposition of the sulphide of ammonium. If the operator has not added a very large quantity of water to the solution of the sulphides of arsenic in sulphide of ammonium, before decomposing by hydrochloric acid, and too large a proportion of acid is subsequently added, the whole of the arsenic is not obtained in the state of sulphide. It is better, in most cases, to decompose the liquor with acetic, instead of with hydrochloric acid.

As Arsenate of Lead. (Pb_3AsO_4).—Arsenic acid is precipitated by a solution of acetate or nitrate of lead, in the state of arsenate of lead, from the weight of which the quantity of the arsenic is determined; but this method is seldom satisfactory, and is attended with more difficulties than that just described, when the solution contains other metallic oxides.

It is also necessary to determine the quantity of the arsenic acid in the arsenate of lead produced, in order to obtain anything like tolerable accuracy; this procedure is much more complicated than the quantitative determination of arsenic in the state of sulphide.

Or, according to Fresenius, if arsenious acid is present, convert into arsenic acid by adding nitric acid and evaporate to a small bulk. Add a weighed quantity of recently ignited pure oxide of lead (about 6 times the quantity of arsenic acid present), evaporate to dryness, and heat to gentle redness for some time. When much nitrate of lead is present this ignition requires considerable care to prevent loss by crepitation. The residue consists of arsenate of lead and oxide of lead; in other words, of arsenic acid and oxide of lead. Subtract the weight of the oxide of lead from that of the residue, and the remainder is the weight of the arsenic acid.

As Arsenate of Magnesium and Ammonium.—In the presence of arsenious acid, add hydrochloric acid, heat gently, add chlorate of potassium in small portions, and then allow to stand at a gentle heat till the chlorous smell has nearly gone off.

Add ammonia in excess (the solution should remain clear), and then magnesium sulphate, previously mixed with ammonium chloride, in sufficient quantity to prevent its being precipitated by ammonia. Allow to stand for twelve hours in the cold. Decant through a weighed filter, transfer the precipitate to the filter with the aid of portions of the filtrate, and then wash with small quantities of weak ammonia (the ordinary solution diluted with 3 parts of water), till the washings are nearly free from chloride. Finally dry the precipitate at 240° Fahr. (100° C.). Its formula is $2(Mg_2(NH_4O)AsO_4) + H_2O$.

The results are always too low, as the precipitate is perceptibly soluble even in ammoniacal water.

Or, precipitate by sulphuretted hydrogen (in the presence of arsenic acid at a temperature of 158° Fahr., 70° C.). Filter, wash, and dry the precipitate. Transfer it as completely as possible to a porcelain dish, add a good quantity of the strongest nitric acid, cover the dish, and after a little while place it on a water bath, then heat till all the sulphur has disappeared and the nitric acid is almost completely evaporated. Extract the filter with ammonia, evaporate the solution to dryness, oxidize the residue with nitric acid, and mix it with the bulk of the arsenic acid. Finally add excess of ammonia, precipitate with a mixture of magnesium sulphate and ammonium chloride, and proceed as above.

Volumetrically. By standard Bichromate of Potassium.—The arsenious acid in the solution to be examined is oxidized by a standard solution of bichromate of potassium, and the excess of the latter is estimated by a standard solution of ferrous sulphate. The solutions are prepared thus:—

Solution of arsenious acid.—Dissolve exactly 5 grm. arsenious acid in potash, add hydrochloric acid in slight excess, then 100 c.c. more hydrochloric acid of 1·12 spec. grav., and dilute to 1 litre.

Solution of bichromate of potassium.—Dissolve about 2·5 grm. to 1 litre.

Solution of ferrous sulphate.—Dissolve about 1·1 grm. iron wire in 20 c.c. dilute sulphuric acid, and dilute to 1 litre.

To find the relation between the chromate solution and the iron solution.—Run into a beaker 10 c.c. of the chromate solution from a burette, add 5 c.c. of hydrochloric acid and 50 c.c. of water, and then titrate with the iron solution till a drop taken out ceases to give a blue colour with a drop of ferricyanide of potassium on a white plate.

To standardize the bichromate solution.—Transfer 10 c.c. of the arsenic solution to a beaker, add 20 c.c. of hydrochloric acid of 1·12 spec. gr., and 80 to 100 c.c. water;* run in chromate solution till the yellow colour of the fluid shows an excess, wait a few minutes, add excess of iron solution, then again 5 chromate solution, finally, again iron solution till the end-reaction appears. Deduct from the total quantity of chromate solution employed the amount corresponding to the iron used.

For the actual analysis.—Dissolve the substance in hydrochloric acid. The solution should contain not less than $\frac{1}{6}$th of its volume of hydrochloric acid of 1·12 spec. gr. It is not advisable, on the other hand, that it should contain more than $\frac{1}{2}$, otherwise the end-reaction with ferricyanide of potassium is slower in making its appearance, and loses its nicety. Now proceed as directed above for the standardizing of the bichromate solution. If the direct determination of the hydrochloric acid is not practicable, precipitate the arsenic with sulphuretted hydrogen; wash the precipitate, transfer it with the filter to a flask, treat it with a nearly saturated solution of mercuric chloride in hydrochloric acid of spec. gr. 1·12, digest on a water bath till the precipitate is white, and dilute with a definite proportion of water. Then proceed as in standardizing the bichromate solution.

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* The water must be measured, for the oxidation is normal only when the fluid contains at least $\frac{1}{6}$th of its volume of hydrochloric acid of 1·12 spec. gr.

Separation from other metals.—Arsenic is separated from lead, mercury, silver, bismuth, cadmium, and copper, by digesting the mixed sulphides in an excess of ammonium sulphide, which dissolves the arsenic sulphides. The solution is subsequently filtered off, and the trisulphide of arsenic thrown down from the filtrate by addition or a slight excess of hydrochloric acid; and on the deposited sulphide being refiltered, washed, dried, and treated as before stated, the amount of arsenic is found. Antimony and tin are most difficult of separation from this metal.

When the arsenic and antimony are in the form of an alloy, they may be completely separated by heating it to redness in an atmosphere of hydrogen or carbonic acid gas, in an apparatus similar to Fig. 11, p. 251; the arsenic thus volatilizes and the antimony remains behind. When the quantity of arsenic is considerable, it is essential that the diameter of the tube, fused on to the further side of the glass bulb containing the alloy, be not too small.

As soon as the apparatus is filled with hydrogen gas, heat is applied to the bulb, and is continued until no more metallic arsenic is deposited in the end tube. By means of a small spirit-lamp, the metal is constantly expelled from the tube, leaving it clear.

When the arsenic has been completely eliminated from the tube, the glass bulb is suffered to cool, but without interrupting the current of gas. It is then weighed with the residuum of metallic antimony, and the loss indicates the quantity of arsenic. It is necessary in this operation not to employ too strong a heat, which would slightly volatilize the antimony. It is scarcely necessary to add, that the operator should take great care not to inhale the arsenical vapours, on which account the experiment must not be conducted in the laboratory, but under the hood of the furnace opening into the chimney-flue.

Nearly all the arsenic found in nature, under the name of *native arsenic*, contains small quantities of antimony, which may be determined by the previous method.

When, however, antimony and arsenic exist in solution, or when the two metals being combined in the solid state are united with other substances, so that the method which has just been described cannot be employed, another process must be adopted to separate them from each other. The solution is diluted with a sufficient quantity of water after having added tartaric acid thereto, without which precaution the addition of water would render it milky.

If the combination under examination consists of a regulus of the metals, it is dissolved in aqua regia, tartaric acid is poured into the solution, and water is then added. A current of sulphuretted hydrogen is next passed through the liquid till it is saturated; it is then very gently heated, in order that the metallic sulphide may settle completely. When the solution contains arsenic acid the first precipitate formed is trisulphide of antimony, and it is only after some time that the trisulphide of arsenic falls down, so that at first a layer of an orange-red colour is deposited, which is covered afterwards by another layer of a pale canary-yellow colour. Before filtering it is necessary to mix these two layers well together by stirring with a glass rod. The whole is then filtered through a weighed filter, upon which the sulphides are dried at an extremely gentle heat until their weight remains constant. After having determined the weight of these sulphides, a portion —about half of it—is shaken down into a glass, the remainder is very gently heated again with the filter, and the whole is weighed for the purpose of ascertaining the weight of the portion about to be operated upon. The portion in the glass is to be treated very cautiously with aqua regia till the sulphides are oxidized.

Tartaric acid is then added to the solution, which is to be diluted with water. If any sulphur has separated, it must be filtered from the liquor, and its quantity ascertained. Chloride of barium is now poured into the filtrate, to precipitate the sulphuric acid which has been formed. From the weight of sulphate of barium, that of the sulphur which it contains is calculated, and the portion of sulphur which has not been oxidized by the nitro-hydrochloric acid is added to the quantity previously determined. The whole of the sulphur contained in a given weight of metallic sulphide having thus been determined, it is easy to deduce the collective weight of the antimony and arsenic.

The quantity of antimony is determined in another portion of the mixed sulphides, in the same manner as directed for that metal. (See ANTIMONY.) When the amount of antimony and sulphur is known, the arsenic is easily found by deducting the united weights of those two bodies from the quantity of the mixed sulphides taken; the difference is the weight of the arsenic.

LEVOL estimates the arsenic which may be alloyed with copper and tin in bronzes as follows:—Having dissolved the compound in hydrochloric acid and evaporated to dryness, nitric acid is added, and the whole heated, which renders the tin insoluble in the form of binoxide or stannic acid, and the arsenious acid partially remains with it. The precipitate is dried and reduced by hydrogen gas. The reduction takes place at a dull red heat, the greater part of the arsenic being separated by sublimation; a small quantity still remains with the tin, but this is removed by treating the alloy with hydrochloric acid, which dissolves the tin, leaving the other constituent undissolved. The compound may also be acted upon by zinc and sulphuric or hydrochloric acid, by which treatment the whole of the arsenic is removed in the form of gaseous trihydride, from which the metal may be abstracted, and its quantity estimated by transmitting the gas through a solution of protoxide of tin of known strength, at a slightly elevated temperature: the arsenic is taken up by the tin, and may be found by the increase of the weight of the latter.

BALSAMS.—*Baumes*, French; *balsame*, German.—This term was formerly applied to all liquid vegetable resins, as well as to a great number of pharmaceutical preparations. French chemists formerly confined the term balsam to vegetable substances composed of benzoic acid with more or less volatile oil. But as this excluded copaiba and some other substances, popularly called balsams, most chemists retain the old acceptation, and consider as balsams the viscid aromatic resinous fluids which exude from many growing plants, whether they contain benzoic acid or not. Balsams are divided into two classes—those which do not, and those which do, contain cinnamic acid.

Oleo-resins.—To the first class belong the different turpentines of coniferous plants; Canada balsam; copaiba; and opobalsamum, or Mecca balsam. They are semi-liquid, resinous, or glutinous juices, which flow spontaneously or by incisions from various vegetables, especially those belonging to the orders Coniferæ, Terebinthaceæ, and Leguminosæ. They have a hot and acrid taste and a strong odour, which in some is very fragrant, in others less agreeable, but still peculiar.

Balsams consist of a volatile oil and resin. The resins are produced by the oxidation of the oils, so that a balsam is an intermediate product between the two. The odour of balsams, their semi-liquidity, and most of their medicinal activity, is owing to the oil which they contain. This oil may be procured from them by distillation: it volatilizes when they are exposed to air, causing them to become hard.

Benzoin and dragon's blood are styled balsams, but more properly belong to the resins, which see. True balsams are more or less viscid liquids, which yield volatile oils on distillation with water.

The class of bodies comprehended under the general name of balsams has not been forgotten in that active investigation of organic bodies to which several chemists have, with peculiar predilection, devoted themselves, especially since the discovery of easier and more certain methods of research than those formerly known have removed the chief difficulties. In former times, the analyses of the balsams were purely qualitative; everything crystalline, and which united with a base, was considered as benzoic acid; those which did not enter into union were described as camphor. If, on distillation, a volatile fluid passed over, it was deemed sufficient to state that the substance contained also a volatile oil. At the present time greater precision is required, and every constituent of a compound is submitted to careful investigation.

CANADA BALSAM; *Baume de Canada.*—This is a turpentine from the Balm of Gilead fir, *abies balsamea*, a conifer which is indigenous to Canada, Virginia, and Carolina. It is slightly yellow, transparent, possesses an agreeable terebinthic odour, and an acrid taste. When fresh it flows readily and is turbid, but in time solidifies and in doing so becomes bright and clear. BONASTRE analyzed this balsam, and found the following:—

	Centesimally represented.
Essential oil,	18·600
Resin, soluble in alcohol,	40·000
Resin, difficultly soluble,	33·400
Elastic resin,	4·000
Bitter extractive and salts,	4·000
	100·000

The sparingly soluble resin is friable, heavier than water, and becomes electrical by friction. A similar balsam is obtained from *abies Canadensis.*

Its index of refraction is 1·532. It turns a polarised ray of light to the right. When exposed to the air in thin layers, it becomes perfectly hard in about forty-eight hours. It is used for cementing together the various parts of many optical instruments, and is of peculiar value in the Nicol prism. Total reflection only takes place when a ray of light escapes from a more refracting to a less refracting medium, but it always, under these circumstances, takes place when the obliquity is sufficient. Now the refractive index of Iceland spar is for the extraordinary ray less, and for the ordinary ray greater, than for Canada balsam. An able optician named NICOL, taking advantage of this, cut a crystal of Iceland spar in two halves in a certain direction. He polished the severed surfaces and reunited them by Canada balsam, the surface of the union being so inclined to the beam traversing the spar that the ordinary ray, which is the most highly refracted, passes from a more refracting to a less refracting medium on passing from the spar to the balsam and is therefore totally reflected; whilst the extraordinary ray passes from a less refracting to a more refracting medium, where total reflection cannot occur, and consequently issues at the other extremity of the instrument.

COPAIBA or CAPAIVA BALSAM (*Baume de Copahu*, French) is obtained from incisions made in the trunk of several species of *Copaifera*, which grow in the Brazils, Peru, Mexico, and the Antilles. The incisions are made in the trees in the rainy season; a single incision often yields 12 lbs. of the balsam.

It is of a light yellow colour, rather liquid, transparent; has a bitter, sharp, burning taste, a suffocating and unpleasant smell; specific gravity, 0·920 to 0·985; soluble in absolute alcohol, partially dissolved by spirit of wine, and gives, with alkalies, crystalline compounds. It dissolves with the aid of a gentle heat one-fourth its weight of carbonate of magnesia, and remains translucent. The analysis yields the annexed:—

	Centesimally represented.
Volatile oil,	38·00
Soluble resins, copaivic acid,	52·75
Brown soft resin,	1·66
Water and loss,	7·59
	100·00

The oil contains no oxygen, has a composition like oil of turpentine, and according to Durand dissolves caoutchouc.

Copaiba balsam is used for making paper transparent, for certain lacquers, and in medicine. In the latter, Pereira states the oil to be preferable to any preparation of the balsam.

Paracopaiba Balsam.—This contains from 20 to 25 per cent. more essential oil than copaiba, which renders it more liquid, but the oils from both kinds of balsam are identical in odour and in all other properties; and the residuous resin in both kinds becomes equally hard and brittle, which entirely does away with the supposition of its having been sophisticated with any fat oil: the two resins, however, differ; the copaiba containing chiefly acid resins, and paracopaiba neutral resins.

Paracopaiba balsam is thinner, and of a lighter yellow colour than the ordinary kind, so that it is strikingly distinguished from the latter by this character. It possesses the disagreeable smell of the balsam of copaiba, and the peculiar persistent taste, in perfect purity. The specific gravity is 0·94. Mixed with solutions of potassa or ammonia, it remains in all proportions turbid, and after some time it again separates from these liquids. In alcohol it does not perfectly dissolve, like the ordinary copaiba balsam, but forms with it a milky liquid. This is on account of its containing a resin, which does not dissolve in alcohol. It contains 82 per cent. of oil and 18 per cent. of resin.

In order to obtain the volatile oil common to the two forms of balsam in a pure state, the balsam is twice distilled with water, and the oil thus procured, which is quite clear, is then dried by chloride of calcium. It is thick, colourless, has a strong and pure copaiba smell, and an acrid, burning taste. Its specific gravity is 0·91; the boiling point is at 485° Fahr. The boiling oil readily becomes decomposed by the heat: it assumes a yellowish colour, becomes viscid, then brown, thick, and glutinous, and at last is perfectly decomposed, whilst carbon is separated. With ether it mixes in all proportions, but not with absolute alcohol, of which a rather large quantity is required for its complete solution. In common alcohol it dissolves with great difficulty; if dry ammoniacal gas be passed into it, it rapidly absorbs it and enters into combination, forming a reddish-brown fluid, which, if saturated, fumes in the air.

This oil is a hydrocarbon, and has the formula C_5H_8. Nitric acid, of 1·32 specific gravity, produces no reaction at common temperatures. If, however, it be heated, a violent reaction takes place, and the oil is converted into a resinous substance. If diluted nitric acid be employed, the mixture boils quietly without coming over, and within a few days the oil dissolves perfectly in the liquid. At the same time nitrous acid, carbonic acid, and peculiar volatile acids, are eliminated, which form, with acetate of lead, a precipitate, but which have not been further examined. The residue being evaporated and diluted with water yields an acid resin not affected by nitric acid, and a crystallizable acid, which remains in solution, whilst the former is precipitated. This resin is of a yellowish-red colour, dissolves in some degree in boiling water, and forms again a milky precipitate when cold. In ether and alcohol it dissolves with facility, and from the spirituous solution small resinous crystals are afterwards precipitated. It has a strong acid reaction, and forms, with potassa or ammonia, red neutral compounds, which are soluble in water.

The acid which is obtained after the evaporated nitric acid solution of the oil has been freed from the resin just described, by the admixture of water, crystallizes in thin, transparent, colourless laminæ. It dissolves easily in water, spirit of wine, ether, and petroleum, is inodorous and bitter, and has a slight acid reaction.

Fuming nitric acid detonates with copaiba oil without the application of heat. Iodine is dissolved by it, without effecting any brisk reaction. Chlorine produces a violent disturbance, hydrochloric acid vapour escapes, and the mass becomes yellow and viscid. Strong sulphuric acid produces a deep violet colour.

OPOBALSAM.—Balm of Gilead.—Mecca Balsam.—This is a whitish, turbid liquid, flowing from incisions made in the *Balsamodendron Gileadense*, or *Amyris Gileadensis*, or Beshan of Arabia. It is very odorous, and on exposure resinifies. Its analysis gives—

	Centesimally.
Volatile oil,	30·00
Soft resin, insoluble in alcohol,	4·00
Hard resin, soluble in alcohol,	64·00
Extractive,	0·40
Loss,	1·60
	100·00

Its physiological effects are believed to be similar to those of balsam of copaiba and the liquid turpentines. It is never employed by Europeans, but the Asiatics use it for its odoriferous as well as its medicinal qualities, and ascribe to it most wonderful properties.

STORAX BALSAM.—This balsam is the product of *Styrax officinalis*, a handsome shrub growing in the Levant, Palestine, Syria, and Greece, and cultivated in the southern parts of Europe, and belongs to the second group of balsams, those containing cinnamic acid.

The storax of commerce comes from Asiatic Turkey. The balsam exudes from incisions through the bark, and when somewhat hardened constitutes the balsamic substance sold by druggists under the name of storax. The bodies thus denominated are, however, very numerous, and of variable character and composition; they are for the most part artificial compounds, utterly dissimilar from the genuine balsam.

Real storax is extremely rare. It occurs in compact masses, of a very fragrant odour and of a rich brown colour, interspersed with white tears, whence the name *amygdaloid styrax*. It was formerly imported enveloped in a monocotyledonous leaf, under the name of cane or reed styrax—*styrax calamita*. In the drug market, two substances are generally met with bearing the name of storax; one of them is called *styrax liquidus;* it is usually of a black, brown, or grey colour, and generally has a disagreeable odour, more resembling that of coal-tar than of the balsam. The other is usually labelled *styrax calamita*, and is a black, brown, or purplish article, either pulverulent or granular, or in the form of agglutinated lumps. Some of it is said to consist of pulverized decayed wood, imbued with a little liquid storax; other samples appear to be fine sawdust, impregnated either with coal-tar or something analogous, and not bearing the remotest similarity to the genuine balsam.

Simon was the first to show that the acid found in storax, and which had always been taken for benzoic acid, possessed all the properties of cinnamic acid; and an analysis of the silver salt by Marchand proved the acid to be the latter.

Storax, as well as the tree producing it, was known to the ancient Greeks and Romans. It is alluded to by Hippocrates, Theophrastus, and Pliny.

Opaque Liquid Storax.—This is imported from Trieste in casks or barrels, holding about 4 cwts. each. It is opaque, of a grey colour, and is of the consistence of birdlime. It has the odour of storax, but frequently intermixed with a feeble smell of benzol or naphthalin.

The substance met with in the shops, and sold to perfumers under the name of strained storax—*styrax colatus*—is prepared from liquid storax, by heating it until the water with which it is usually mixed is evaporated and then straining it. During the process, it evolves a very fragrant odour. The impurities are stones, sand, *et cetera.*

Pellucid Liquid Storax.—*Storax liquide pur*, Guibourt.—This substance is a pellucid liquid, having the consistence and tenacity of Venice turpentine, a brownish-yellow colour, a sweetish storax or vanilla-like odour, entirely different from that of liquidambar. A few particles of bran or sawdust are commonly intermixed with it. By keeping, it yields a white and acid sublimate on the sides of the bottle which contains it.

All the storax imported into this country comes from Trieste. The following are the results of Reinsch's analyses of styrax calamita:—

	1. Styrax calamita.	2. Brown granular.	3. Reddish compact.
Volatile oil,	?	0·5	0·4
Resin,	41·6	53·7	32·7
Sub resin,	?	0·6	0·5
Benzoic acid,	2·4	1·1	2·6
Gum and extract,	14·0	9·3	7·9
Matter extracted by potassa,	15 0	9·6	23·9
Woody fibre,	22·0	20·2	27·0
Ammonia,	traces.	stronger traces	strongest traces
Water,	5·0	5·0	5·0
Styrax calamita,	100·0	100·0	100·0

The volatile oil was obtained by digesting the distilled water of storax with ether. The *solid* oil was white, crystalline, and fusible; its odour was agreeable, its taste aromatic and warm. The *fluid* oil had a less penetrating odour.

Simon found liquid storax to consist of styrol, cinnamic acid, styracin, a soft and a hard resin.

Storax is used in medicine, and is called a stimulating expectorant. In its operation it is closely allied to balsam of Peru and benzoin, but it is less powerful than the latter. It is used also as a detergent in the form of ointment.

LIQUIDAMBAR is obtained from the *liquidambar styraciflua*, a tree which grows in Mexico, Louisiana, and Virginia. There are two varieties, the one thin like oil, and the other thickish like turpentine. The former is the balsam as it runs from the tree; the latter is the form it assumes after exposure to the air. It is transparent, amber-coloured, has an agreeable and powerful smell, and an aromatic taste, which is somewhat pungent in the throat. Boiling alcohol dissolves it almost entirely. It contains a good deal of benzoic or cinnamic acid, some of which effloresces when the resin hardens, as it does with keeping.

TOLU BALSAM is the produce of *Myrospermum toluiferum*, a tree growing on the mountains of Tolu and Turbaco, and on the banks of the Magdalena, between Garapatas and Monpox. It exudes during the heat of the day from incisions in the bark; and is imported chiefly by way of New York and Jamaica, generally in tin canisters, but sometimes in earthen crocks and in calabashes. On its arrival it is soft and tenacious, but gradually hardens; it is translucent, brown, very fragrant, and has a sweetish taste, softening between the teeth. When heated, it fuses and takes fire, diffusing an agreeable odour. The tree which yields the balsam of Tolu was formerly called *Toluifera balsamum.* Richard having carefully investigated the characters of the genus Toluifera, found that, with the exception of the fruit, they were identical with those of the genus now called *Myrospermum;* and as Ruiz states that the balsams of Tolu and Peru are obtained from the same tree, the *M. peruiferum* has been adopted by several writers, and by the London College, as the source of both balsams. Richard made a distinct species of the tree yielding the balsam of Tolu, and it is now called *M. toluiferum.*

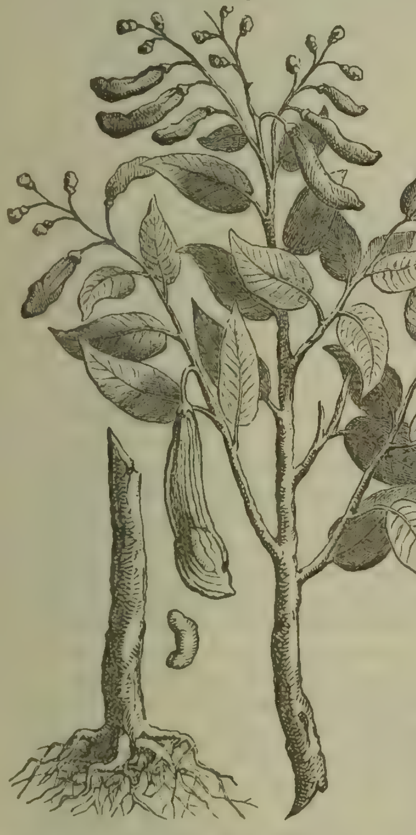
Tolu balsam contains a volatile oil, cinnamic acid, and two resins; the one soluble, the other insoluble in alcohol. The volatile oil is tolene (Kopp) and is isomeric with oil of turpentine, $C_{10}H_{16}$. On distilling Tolu balsam, Muspratt remarks:—There passes over at first aqueous vapour, and when the temperature is sufficiently elevated, a large quantity of benzoic, with a slight admixture of cinnamic acid, which solidifies immediately in the recipient into a white crystalline mass. When the fluid distilling over no longer solidifies, the receiver is charged; a yellow liquid condenses. The crystalline mass collected in the first receiver contains likewise a large quantity of the same liquid, which can be separated by mere distillation with water. Kopp states that the benzoic acid is a product of decomposition, and does not exist in the balsam itself.

Balsam of Tolu is frequently adulterated with common resin To detect this, pour sulphuric acid on the balsam and heat the mixture. The balsam dissolves to a cherry-red fluid, without evolving sulphurous acid, but with the escape of benzoic or cinnamic acid, if no common resin is present; on the other hand, it foams, blackens, and much sulphurous acid is set free, if it is thus adulterated.

PERU BALSAM.—*Balsamum peruvianum*, *Balsamum indicum.*—There are three varieties of this balsam, viz:—White Peru balsam, dry Peru balsam, and black Peru balsam. Of these, the black only has any practical applications. They are alike the produce of the *Myroxylum*, or *Myrospermum*, a tree growing on the coast of San Salvador, Central America.

The earliest mention of Peru balsam is made by Nicolas Monardes in 1565; he calls it simply *balsamo*, and says that it is the produce of a tree growing in New Spain, and called by the Indians *xilo.* He mentions two modes of procuring the balsam—one by incision into the rind of the stem, the other by boiling the branches in water; and he afterwards notices its physical properties and valuable medicinal qualities.

Fig. 1.



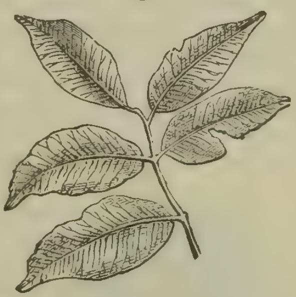
Francisco Hernandez, a Spanish physician and naturalist, who resided from the year 1593 to 1600 in Mexico and New Spain, notices four balsam trees: one called *Hoitziloxitil*, a second named *Huaconex*, and a third denominated *Maripenda*, and the fourth found in the province of Tolu. Of these four, the first appears to be identical with the tree which yields the so-called balsam of Peru; a copy of Hernandez's drawing of it is subjoined—Fig. 1.

Hernandez states that the Indian balsam tree—*arbor balsami Indici*—is called by the Mexicans *hoitziloxitil*, because it abounds in resin. He describes it as being of the size of a lemon tree, and having leaves which are larger than those of the almond, but rounder and more acuminate. The flowers are yellow, and are placed on the summits of the branches. The seeds are whitish, oblong, somewhat contorted, and lodged at the extremity of the oblong shells or fruits, which are longer and broader than the leaves. The tree, he says, was cultivated by the Mexican kings in the Hoaxtepec gardens. He also states that the seeds yield by pressure an oil, which resembles in flavour and odour that obtained from bitter almonds and peach kernels.

After the death of Linnæus, who had always been particularly anxious to ascertain the plant which yields this balsam, Mutis sent to the younger Linnæus specimens of the leaves and flowers of a plant which, he said, grew in the warmest provinces of South America and yielded Peruvian balsam; subsequent investigation has, however, proved this statement to be erroneous, as will be seen further on. A description of this plant, to which the name of *Myroxylon peruiferum* was given, was published in the *Supplementum Plantarum.* Fig. 2 is a sketch of the leaflets of *Myroxylon peruiferum.* The figure is about one-third the natural size of the leaf.

The first accurate botanical description of the tree which really yields balsam of Peru was given by Ruiz, in 1792, in his *Quinologia.* Ruiz says the tree is known in Peru under the name of *Quinoquino*, and he calls it Myroxylon peruiferum, considering it to be identical with the *M. peruiferum* sent by Mutis to the younger Linnæus. This, however, is an error, Ruiz's plant being, according to Kunth and De Candolle, a distinct species from that of Mutis. Ruiz states that the tree grows in the mountains of Panatahuas, in the forests of Puzuzu, Muna, Cuchero, Paxatin, Pampahermosa, and in many other countries near the river Maranon, in low, warm, and sunny situations; but the Indians of these places do not collect the balsam.

Fig. 2.



Ruiz says the balsam of Quinoquino is procured from incisions made in the tree at the beginning of spring, when the showers are gentle, frequent, and short; it is collected in bottles, where it keeps liquid for some years, in which state it is called *white liquid balsam.*

In 1823 appeared the sixth volume of Humboldt, Bonpland, and Kunth's *Nova Genera et Species Plantarum.* In this work the plant of Ruiz, called by him *M. peruiferum*, Linnæus, is denominated *Myroxylum pubescens*, and the designation *Myroxylum* *peruiferum* is retained for the plant sent by Mutis to Linnæus. These distinctions have been adopted by De Candolle, who, however, has followed Jacquin, and designated the genus *Myrospermum*, instead of *Myroxylon* or *Myroxylum*. But it is most unfortunate that the specific name *peruiferum* should be retained for a plant which does not yield the so-called Peruvian balsam.

In 1834 M. Bazire stated that the so-called balsam of Peru was not the produce of Peru, but of the coast near Sonsonate. He forwarded some of the fruit to Europe, when it proved to be that of the *Myrospermum pubescens* of De Candolle, and not that of *Myroxylum peruiferum*.

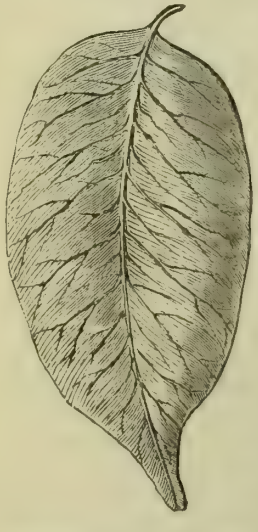
The uncertainty which existed respecting the origin of balsam of Peru was finally cleared up by Mr. Skinner, who procured for Dr. Pereira specimens of the tree and balsams from Central America, and furnished him with the following facts:—

1. The tree which yields the black and white balsams of Peru is the species described and figured by Ruiz, the *Myrospermum pubescens* of De Candolle.
2. Black balsam, the balsam of Peru of commerce, is obtained by incision from the stem.
3. The white balsam is procured from the fruit by pressure.
4. Both these balsams are exclusively obtained from the so-called Balsam Coast in Central America.

Dr. Pereira, however, doubts whether the *Myrospermum* of Sonsonate, from which balsam of Peru, white balsam, and balsamito, are obtained, is identical with that figured by Ruiz, and which, according to both Kunth and De Candolle, is *M. pubescens*. He, therefore, designates the plant the *Myrospermum of Sonsonate*.

The branches are terete, warty, but otherwise smooth, ash-coloured, or ash-brown.

Fig. 3.



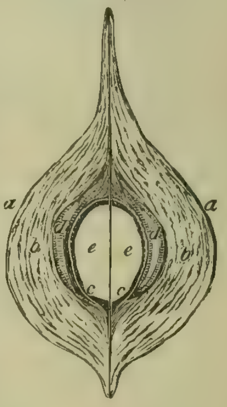
The leaves are alternate, petiolate, and imparipinnate. The common petioles appear to the naked eye devoid of hairs, but when examined by the microscope are found to be covered with a few short ones.

The leaflets are from five to eleven, alternate with short petioles. Fig. 3 represents one of these leaflets in its natural size. Exclusive of foot-stalk, their length varies rom about 2 to $3\frac{1}{2}$ inches; and their greatest width from 1 to $1\frac{1}{2}$ inch. The most usual size is 3 inches in length, and $1\frac{1}{4}$ to $1\frac{4}{10}$ths of an inch in breadth. Their general shape is oblong or oval oblong, in some cases ovate. They are round, or very slightly tapering, not cordiform at the base. Superiorly they contract abruptly into an emarginate point. To the naked eye the partial petioles and mid-ribs appear devoid of capillæ, but when examined by the microscope short lymphatic hairs, having a glossy or resinous appearance, are distinctly visible on them; and the partial petioles appear somewhat rough from transverse rugæ. The leaflets are elegantly marked by rounded and linear pellucid spots; the lines being usually parallel with, or in the direction of, the primary veins. To see the spots, the leaflets must be held up against a strong light, and examined by a magnifier.

The fruit is a one-celled, one-seeded, winged, indehiscent pod, called by some a samara, by others a samoroid legume. The fruit-stalk is naked at the base, but is amply winged superiorly. The fruit, including the winged foot-stalk, varies in length from about 2 to 4 inches; the usual length is $3\frac{1}{8}$ or $3\frac{1}{4}$ inches. At the peduncular extremity the fruit, or rather its winged foot-stalk, is rounded or very slightly tapering, unequal-sided; at the summit it is enlarged, turned, and rounded with a small point—the remains of the style—at the side. The mesocarp is fibrous; but immediately exterior to the endocarp it contains, in receptacles, a yellow oleoresinous or balsamic juice, which by age hardens and resinifies. Ruiz, Kunth, Endlicher, and De Candolle, describe this juice as immediately surrounding the seed, and being between it and the lining—endocarp—of the shell; but this is a mistake, it is exterior to the endocarp.

The principal part of the balsam resides in the two receptacles or *vittæ*, one placed on either side; but if a transverse section of the fruit be examined by the microscope, numerous receptacles of the more or less dried balsam are perceived in all parts of the mesocarp. In the two larger receptacles, the balsam is usually found in the liquid state; but sometimes the walls of the receptacles are lined with the crystallized balsam (the *myroxocarpin* of Stenhouse). That the balsam resides in the mesocarp, and not in the cavity of the fruit, is proved by the cross section, which shows that the paries of the cavity of the fruit is continuous with the two sutures. The seed lies loose and dry in the cell of the pericarp, and is covered by a thin, white, membranous coat—testa. The cotyledons are yellowish and oily, have an agreeable odour, like that of the tonka-bean or melilot, and a bitter taste, somewhat resembling that of bitter almonds. By digesting the seeds in ether, a tincture is obtained which yields on evaporation a very agreeable-smelling, amber-coloured, soft extract, the odour of which resembles that of the cotyledons. Fig. 4 is a cross section of the fruit and seed, magnified:—*a a*, epicarp; *b b*, mesocarp; *c c*, endocarp; *d d*,

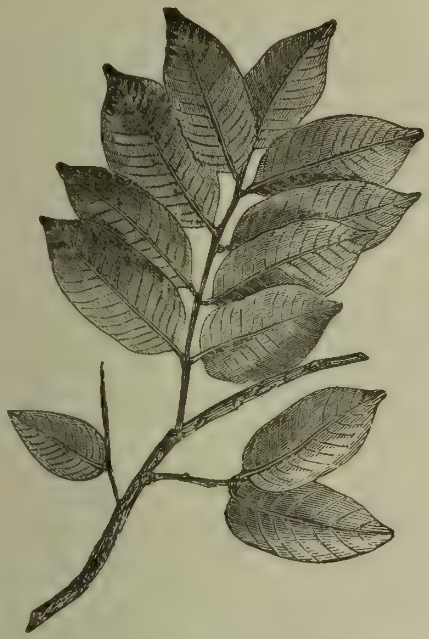
Fig. 4.



large vittæ, or lacunæ, containing balsam; *e e*, cotyledons.

In the annexed sketches, Fig. 5 shows a leaf-bearing branch of the Myrospermum of Sonsonate, about one-third the natural size; Fig. 6, a fruit-bearing branch; Fig. 7, vertical section of the fruit; Fig. 8, lateral section of the fruit, showing the seed *in situ.*

Fig. 5.



Central America is the country of the Myrospermum Sonsonate. It grows on the Balsam Coast—between 13° and 14° north latitude, and 89° and 90° west longitude—in the state of Salvador, where the black and white balsam are exclusively obtained from it. HERNANDEZ gives Panuco as one of the places where it grows; and CLAVIGERO states that it is common in the provinces of Panuco and Chiapan.

Fig. 6.

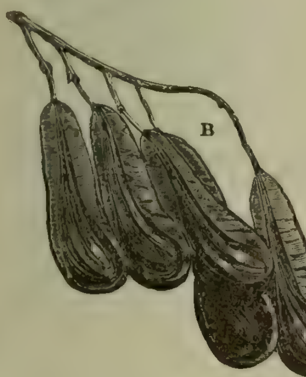
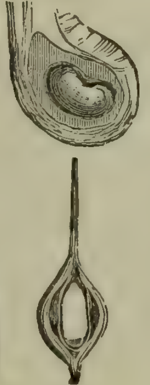


Fig. 7.



Various medicinal products are obtained from the tree. By making an incision in the trunk of it, a liquor exudes called the "black balsam," an admirable remedy for effecting the speedy cure of wounds of every description: from the flowers the "spirit of balsam" is made; the seeds or nuts produce the "oil of balsam," an excellent anodyne; and the capsules yield the "white balsam."

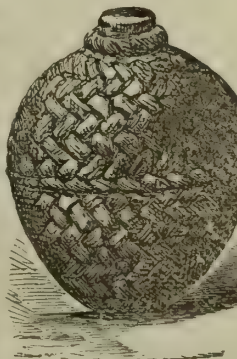
From these simple balsams the "tincture" or "essence of balsam" is extracted. It is generally termed *balsamito*, and was a discovery of DON JOSE EUSTAQUIO DE LEON, director of the mint in Guatemala, who published a description of the many virtues of this peculiar medicine. The only medicinal products of the tree are, black balsam—commonly called balsam of Peru—white balsam, and balsamito.

White Balsam of Peru.—This balsam is quite neutral to test paper, and has a peculiar agreeable odour like melilot. It was observed by STENHOUSE that when white Peru balsam is digested in ordinary alcohol, a considerable portion readily dissolves; and when the clear extract is allowed to repose for a day, it deposits a quantity of large white crystals, to which he gave the name Myroxocarpin. They retain a good deal of adhering resinous matter, which can be removed by digestion with a little animal charcoal and repeated crystallizations from hot alcohol. When pure, they are hard and brittle, colourless, tasteless, scentless, and form broad thin prisms, more than an inch in length. Myroxocarpin is insoluble in hot and cold water; but is readily dissolved by hot alcohol and ether. To these crystals STENHOUSE has applied the name. The formula of Myroxocarpin is $C_{48}H_{70}O_6$. It does not unite with either acids or alkalies, and is not decomposed by a solution of potassium or sodium hydrate.

Myroxocarpin fuses to a transparent liquid, which does not crystallize on cooling; but when redissolved in hot alcohol it reassumes the crystalline form on evaporating the solution. By chlorine it is converted into an amorphous resin. Heating with nitric acid decomposes it into oxalic acid and an uncrystallizable resin.

The Sonsonate or St. Salvador white balsam—*balsamo blanco*, is often confounded with the balsam of Tolu. White balsam is obtained at Sonsonate by pressure, without heat, from the interior of the fruit and seed. It is imported in globular earthen jars, surrounded by a kind of plaited matting—Fig. 9—closed by an earthen stopper. The jar inclosed in the matting is about 1 foot high, and 10½ inches in diameter, and contains about 20 lbs. of balsam, which is partially concreted or crystallized on the sides. When removed from the jar, and put into a white glass bottle, it closely resembles in appearance strained American or Bordeaux turpentine. It is semifluid, or a soft solid, and by exposure becomes

Fig. 9.



firmer. It is quite devoid of the fragrant cinnamon odour of the black balsam of Peru and balsam of Tolu.

According to SKINNER'S account, the balsam is obtained thus:—A fire is made around, but at some little distance from the balsam tree; the bark is then cut, and a stick slipped in between it and the wood, so as to partially separate these two parts of the stem from each other. By working the stick about, somewhat in the manner of a pump-handle, the balsam, aided by the heat, exudes and is absorbed by rags.

The only purification to which balsam of Peru is subjected in England is mechanical; that is, the balsam is, by standing, allowed to separate from the water and other impurities, and is then drawn off.

M. SARAVIA, of Sonsonate, having questioned the Indians respecting the production of balsam, states that the method used to extract the balsam from the trees is to make several incisions, over which pieces of old cloth or rags are placed for the absorption of the juice; when they are well soaked, they are put in water to boil, until they have discharged the greatest part of the imbibed balsam. The liquid is then allowed to settle sufficiently, until the water rises, leaving the balsam at the bottom; next, the upper stratum is carefully poured off, and the balsam put into gourds, although at this time it is not very pure. The rags are then put into "redes," little bags of cords, which are strongly twisted to wring out any remaining balsam into the gourds. When purchased, it is necessary to clean it again, because it still contains water and other impurities, which some Indians will mix with it to gain greater weight.

Black Peru Balsam; the Sonsonate of St. Salvador; black balsam.—This is the balsam of Peru of commerce—*Balsamum Peruvianum*, Latin. At Sonsonate it is termed *black balsam—balsamo nigro*. It is sometimes denominated the *black* or *liquid balsam* of Peru. Sonsonate or St. Salvador black balsam of commerce (the balsam of Peru of the shops) is exclusively the produce of the Balsam Coast, which extends from the Ajacutla to the Port Libertad on the Pacific side of Central America.

The varying methods of obtaining black Peruvian balsam causes great differences in the product; and besides this the various kinds of Myrospermum used for yielding the balsam, the higher or lower degree of heat employed in its preparation, all contribute to vary the quality obtained.

SKINNER says the method employed by the Indians of Central America for extracting the black balsam from the tree is as follows:—They begin by making an incision from 2 to 2⅓ inches broad, and from 3½ to 4 in length; they then raise the bark from the living wood, and afterwards apply there pieces of cotton rags, after having heated the tree by surrounding it with a brisk fire for a short time. When they tap the tree for the first time, they make the incision rather more than a yard above the ground, and when the liquor ceases to ooze out, they make a second incision by the side of the first one, and in the same manner, but a little higher up; and thus they continue making new incisions as fast as they become exhausted around the tree. In the course of ten or twelve days the rags become thoroughly impregnated with a thick olive-brown liquid; they are then withdrawn, and subjected to a fresh process. The rags saturated with the balsam are collected together and placed in an earthen vessel, called olla or pot, with some water, and boiled for five or six hours. During this operation the balsam detaches itself, and so long as the boiling continues mixes with the water; but as soon as the liquid becomes cold, the balsam, being much heavier, settles, and the water floats over it; hence it is easy to separate them from each other. Before the water cools, the cotton rags are removed; but as they still contain a certain quantity of liquid, they are subjected to a more forcible pressure by means of a small machine, made with pieces of wood, cords, and tourniquets. Lastly, they collect all the balsam extracted from these rags, after subjecting them to pressure for several days; pour off the water, and put the balsam, which has now become dark and liquid, into a calabash, for the purpose of carrying it to market. The balsam which flows from the tree always contains a considerable quantity of water, and hence the necessity of boiling this liquor after it has been extracted.

Balsamum Peruvianum nigrum is generally exported from Sonsonate and Ajacutla, Central America, in jars, after being deprived of its water, mucilage, and salt (which is generally effected in a tub); and is transferred to Europe in tins. A considerable quantity of water is still retained and commonly separates in the course of the voyage. In a fresh state the balsam is greenish and more fluid than after having been kept for some time, when it becomes a deep brown, opaque in the mass, but in thin layers transparent and of a golden red colour.

The characteristics to be noted in the judging of its genuineness are:—Its agreeable odour resembling that of vanilla, complete miscibility with alcohol, by which the absence of fixed oil is shown, and its suffering no diminution of volume after mixing with water, proving that there is no spirit present. A sign of its purity, according to MUSPRATT, is that 1000 parts of it should saturate 75 parts of crystallized potassium carbonate, it having an acid reaction.

Black Peru balsam is viscid, but not glutinous; on exposure to air its viscidity increases, but it does not solidify. Its taste is peculiarly bitter and irritating. When heated, it takes fire and burns with a smoky flame. It mixes with absolute alcohol in all proportions, but deposits a flocculent precipitate on standing. On distillation with water, black balsam of Peru yields cinnamic acid. Sulphuric acid converts it into a thick red mass, with evolution of sulphurous acid. When two volumes of balsam of Peru are heated with three volumes of solution of potassium hydrate, 1·3 specific gravity, two layers of liquid are produced: the lower consisting of cinnamic acid, resins, and various colouring matters; and the upper of a brownish oil, which is termed oil of balsam of Peru.

Balsam of Peru was first analyzed by STOLTZE, who found:—

	Per Cent.
Brown slightly soluble resin,	2·40
Brown resin,	20·70
Oil—cinnamein ($C_7H_7,C_9H_7O_2$),	69·00
Cinnamic acid ($C_9H_8O_2$),	6·40
Extract,	0·60
Loss and moisture,	0·90
	100 00

FREMY describes the balsam as consisting of varying quantities of cinnamein or styracin ($C_7H_7,C_9H_7O_2$), an isomeric crystallizable substance, metacinnamein, cinnamic acid ($C_9H_7O_2$), and resin. The various components are separated by dissolving the balsam in absolute alcohol and adding alcoholic potassium hydrate solution, which precipitates the resin. The cinnamein is next precipitated by adding water, and purified from resin by solution in petroleum, and evaporation. The remaining solution will contain cinnamic acid only.

Cinnamein ($C_7H_7,C_9H_7O_2$), or cinnamate of benzyl, is a volatile oil of a feeble, rather pleasant odour, but a sharp aromatic fatty taste; it produces grease spots on paper. It is nearly insoluble in water, but dissolves readily in alcohol. It absorbs oxygen from the air, and acquires thereby a rank odour and an acid reaction. Its specific gravity at 60° Fahr. (15°·5 C.) is 1·0975.

Balsam of Peru is frequently adulterated with castor oil and copaiba balsam, &c. Fixed oils are detected by their remaining insoluble in alcohol; volatile oils can be distilled from the aqueous mixture of the balsam; sugar and like bodies are discovered by the diminution in volume which the adulterated balsam evidences when shaken up with water.

Considerable variations occur in the specific gravity of Peru balsam, which must not be altogether overlooked. It usually varies between 1·14 and 1·16; but when sophisticated with as much as 25 per cent. of castor oil, it is much lower.

To detect copaiba balsam, the substance is to be heated in a small tube retort, until a few drops of a yellow oily liquid have passed over, which takes place at a temperature of 374° Fahr. This distillate is acid, and soon deposits crystals of cinnamic acid. If the balsam used was pure, it solidifies completely; but when adulterated with copaiba, the crystals float in copaiba oil. The distillate is then to be saturated with caustic potassa, and a solution of cinnamate removed by means of blotting-paper. The drops of oil which are then left mix quietly with iodine if the balsam was pure, but cause a violent action in the presence of copaiba.

An expert chemist can detect the presence of copaiba by its smell; in general, the purity and strength of the vanilla-like odour of the Peru balsam, and its perfect transparency, are some proofs of its goodness.

Black balsam of Peru is used in confectionery, in lozenges and chocolate, as a substitute for vanilla; in perfumery it is employed to scent pomatums, sealing-wax, &c. The once celebrated "Pomade Divine" contained a large quantity of balsam of Peru. One of the best recipes, according to URE, was:—

Fine olive oil,	18 ozs.
Balsam of Peru,	1 oz.
Aris root,	6 drachms.
Storax,	1 drachm.

This mixture, with some bruised nutmegs and cinnamon, was macerated in a water bath for three hours and then filtered. The resulting aromatic oil was mixed with 6 ozs. of white wax and 1 oz. of spermaceti; these were mixed together, and a few drops of the essential oils of nutmegs, cinnamon, and cloves added.

In medicine balsam of Peru is used as an application to wounds, and also as an internal remedy.

Dry Peru Balsam—*Balsamum peruvianum siccum, Opobalsamum siccum.*—This substance is said by WEDDELL to exude spontaneously from the myroxylum, and to harden as it comes in contact with the air. FROMSDORFF gives its composition as:—

	Per Cent.
Cinnamic acid,	12·0
Volatile oil,	0·2
Resins,	88 0
	100·2

Its colour is reddish yellow; it is hard, transparent, smells like vanilla, melts when heated, and burns with a smoky flame.

BEER—*bière*, French; *bier*, German—the spirituous liquor made from any farinaceous grain, but more especially from barley. The grain is first malted and ground, then its soluble part extracted by hot water. This extract or infusion is concentrated by boiling in caldrons, and hops, or some other plant of an agreeable bitterness, added. The liquor is then allowed to ferment in vats. The term beer is also applied to fermented liquors made from ginger, spruce, and molasses, as well as to that procured from malt and hops.

In this country beer is of different degrees of strength, and is denominated small beer, ale, porter, brown stout, &c., according to the quantity and nature of its ingredients. In the United States beer is the name given to fermented liquors made of various materials besides grain. When a decoction of the roots of plants forms part of the composition, it is called "spring beer," from the season in which it is made. There is also "root beer."

In the time of TACITUS, whose treatise on the manners of the Germans was written about the end of the first century of the Christian era, beer was their common drink: PLINY mentions it as being used in Spain, under the name of *cælia* and *ceria*; and in Gaul, under that of *cerevisia*; he then proceeds to explain that almost every species of corn has been used for the manufacture of beer.

These observations are corroborated by other ancient authors. The *cerevisia* of PLINY evidently takes its name from *Ceres*, the goddess of corn—philologists doubting whether it ought not to be written *cererisia*. PLAUTUS more minutely calls it *Cerealis liquor*; that is, liquor used at the solemn feasts in honour of that goddess—the *harvest home*: and both he and COLUMELLA—a famous writer on agriculture, a contemporary of CLAUDIUS, and whose work is therefore coeval with the invasion of Britain by that emperor—called this liquor *zythum*, which if traced back to its Greek origin is interpreted, "drink from barley."

In Europe beer is usually made from barley; in India from rice; in the interior of Africa, according to MUNGO PARK, from the seeds of the *holcus spicatus*, a species of couch grass.

In the brewing of beer, the first process of importance which comes under notice is that of malting. Ere this can be proceeded with, however, the grain on which to operate must be chosen, and it is hoped the few following remarks will be found of service, more especially to the inexperienced.

SELECTION OF BARLEY.—The barley most suitable for conversion into malt grows in large hedgeless tracts of light calcareous soil, and crops, excellent in quality, also thrive on rich loam. Much, however, depends upon the seed: the best possesses a bright, clean, thin, wrinkled husk, tenaciously adhering to a plump, round, well-fed kernel, which, when bruised, appears chalky and sweet, with a germ full, and of a pale yellow colour. If the barley breaks with a flinty fracture it must be rejected. The barley most profitable for malting is the "rath," or early ripe, which matures several weeks before other sorts, and is that which agriculturists ought to select, not only on account of its forwardness, but also because it makes superior malt, in consequence of the thinness of its skin and the lusciousness of its nature. Barley is not in a proper condition for malting until it has sweated and seasoned in the stack; if stacked too damp it will generate so much heat as to destroy the germ. The maltster should be careful to avoid mixing old and new barley, as these never grow evenly or simultaneously on the malting floors, and consequently do not work well together.

Adept brewers, from their long experience, know the best kinds of grain to select.

MALT AND MALTING.—Oats, peas, beans, maize, buckwheat, and common wheat, are all capable of being malted, and have been experimented upon, but barley is almost exclusively used for this purpose.

The heaviest grain is recommended, as, if in good condition, it gives malt of corresponding gravity.

What is here technically understood by "heavy malt" is, that it shall be tender and friable throughout, and without hard ends. Perfect malting is not always attainable, even with the best skill and management, and it would on this account be improper to pass lightly or carelessly over such an important subject.

Malt may be very heavy and yet too hard properly to bear the name of malt; and inexperienced brewers may be greatly deceived, unless they have sufficient knowledge to discriminate between the several varieties sent into the market.

If the extract from the malt is deficient, in comparison with that of the best quality, it is also deficient in fine flavour.

The utmost skill is required to produce a malt of abundant sweetness and friability: when these are attained it will never be too heavy.

If the brewer is also a maltster, as he ought to be, both in knowledge and in practice, he can procure malt any colour he pleases; but even if he be not, there is no difficulty in obtaining malt of any peculiar tint or flavour he desires.

The whole process of malting is comprised under four successive operations: "Steeping," "Couching," "Flooring," and "Kiln-drying."

The excise regulations press with great severity upon the maltster. Malting is regulated by the Act 7 and 8 George IV. cap. 52, and 11 George IV. cap. 17. The steeping vessel must be of a certain specified size and construction, and must have been approved of by the excise office. As URE points out, the law allows the maltster no option, though from the uncertain character of grain it might be inferred that the process of steeping would be left to the judgment of the maltster, who would determine, according to his experience and the nature of the resulting phenomena, when the grain had been steeped long enough in the water. Whether the grain be old and dry or new and moist, "maltsters are required to keep their corn or grain covered with water for the full space of forty hours, under the penalty of £100." Nor will any change occurring in the appearance of the grain, and seeming to require its immediate removal, justify or excuse the maltster in so doing, unless indeed he shall have anticipated the occurrence by giving notice of his intention to do so in his original notice "to wet" (which must date twenty-four hours previous to the commencement of that operation), and give the day and hour of the day for beginning the "steep," all under the usual penalty of £100. Nor may he "begin to wet at any other time than between the hours of eight in the morning and two in the afternoon," under a penalty of £100; nor may he take corn or grain from any cistern at any other time than between the hours of seven in the morning and four in the afternoon. To empty corn or grain out of any cistern, until the expiration of ninety-six hours from the time of the last preceding emptying of any cistern in the establishment, involves a penalty of £200; and the same infliction occurs "if the grain be not emptied out of all such cisterns at one and the same time, or within three hours after the clearing of the first cistern was commenced.

Maltsters are not to mix, either on the floor or kiln, any corn or grain of one wetting with corn or grain of another wetting, under a penalty of £100.

The power of loosening or compressing the grain when on the couch, according to its temperature, would evidently much improve the formation of malt, but here again the maltster is restricted; the grain has been gauged in the steep, and again on the "couch," or place where it is laid to germinate, and if the maltster should any way compress it, so as to diminish its bulk, he incurs a penalty of £100. Again, if too little water or too much water is absorbed by the grain during steeping, no subsequent manipulation of the grain is allowed unless the grain has been in the steep for fifty hours, when, after six days (144 hours), the maltster may sprinkle it with water. If the grain has been at first insufficiently wetted it desiccates about the end of the third day, ceases to germinate, evolves a sickly odour, and becomes mouldy, so that the relief afforded by the law is more in appearance than reality. URE states that such is the great urgency for the sprinkling on the third day, that "it is an undeniable fact that, in spite of the heavy risk incurred (£200), maltsters do almost invariably sprinkle their floors at about this period."

The excise officer makes three separate gauges of the grain—1, in the steep; 2, on the couch; 3, on the floor: of these he must select the largest for charging duty upon. Thus, if he finds that "the cistern or couch gauge exceeds the floor gauge, then the best cistern or couch gauge will be the charge; but if that be less than the floor gauge then the floor gauge will be the charge." Any accident or loss arising after the "steep" is thus thrown wholly upon the maltster; and the carelessness, malice, or ignorance of common workmen may at any time subject the honest maltster to charges of dishonesty and penal inflictions.

The chemistry of malting has been already described at page 58 (ALCOHOL). We give here Dr. GRAHAM'S description of the botanical change. Inside the grain, or rather "caryopsis," of barley is a large amount of starchy matter, which is termed by botanists "albumen." At the base of this starchy matter is the young embryo of the future plant. Now when the seed of the barley is moistened, provided there is a moderate degree of heat, it will gradually swell, presently the skin will burst, and at the lower end the radicle or small rootlet will gradually protrude. After that has taken place there is from the upper surface of the embryo a gradual prolongation of the plumule of the young plant.

The important points about the process to consider are the following:—First of all, the young seed gets warm, gives out carbonic acid, and the so-called albumen, or starchy matter of the cotyledons, is gradually used up and consumed; in other words, the young plant is in this stage of its existence really not yet hatched, but is still, from a chemical point of view, very much like the chick in the ordinary egg; and GARTNER, the physiologist, who first of all gave the term albumen to the starchy matter surrounding the young embryo, was perfectly right from a physiological point of view to call it so, since it serves the same functions which the white of an egg does to the embryo inside a hen's egg. It is a store of food laid up there by the parent. It gradually diminishes, and as it diminishes the young plant or the young animal gradually increases in bulk. Finally, the young plumule bursts through the upper end, and in process of time comes in contact with the atmosphere.

In this process all that is needed is a small amount of moisture and a small amount of heat, because barley grows well even in the north of Scotland.

Steeping.—As stated above, steeping is to cause the grain to absorb the necessary amount of moisture to start the germination, which is requisite before its starchy matters, the "albumen," can be converted naturally into glucose.

The steeping is usually performed in large wooden or stone cisterns, into which the grain to be malted, already screened down and nicely levelled, is shot; it must be charged with liquor to 6 or 7 inches above the barley, and although the grain has been well cleaned, there may be some light grains and other matters floating on the surface of the liquor; these must be skimmed off, since if allowed to remain they would impair the quality of the malt, and also the flavour of the beer made from it. However, the improved cultivation of the soil, and the new varieties of barley, have of late years done away with the necessity of skimming.

In consequence of the absorption of moisture, the grain swells about one-fifth in bulk, and increases about 50 per cent. in weight, 100 lbs. of barley thus becoming 150 lbs.

The object of steeping is to expand the farina of the barley with humidity, and thus make the seed fit for germination, when subsequently exposed to the air. Too much steeping is injurious, because it prevents the germination at the proper time, in consequence of the air being excluded whilst the superabundance of water is spontaneously evaporating; it is hurtful, also, on account of its extracting a portion of the saccharine matter. The maceration is known to be complete when the grain may be easily perforated with a common needle, and is swollen to its full size; or if a barley-corn, when taken between the thumb and fingers and pressed, sheds its flour upon them, it is ready; but if it continues entire, or its substance exudes as a milky juice, it is either, in the first instance, not sufficiently steeped, or, in the latter, the steep has been too long continued, and the grain is spoiled for germination.

In warm weather it sometimes happens that, before the grain has sufficiently swelled, the water becomes acid, from the production of acetic or lactic acid; this can be ascertained by testing with blue litmus paper, and may be immediately remedied by drawing off the foul liquor by means of the tap at the bottom of the cistern, and replacing it with fresh cold water. No harm is done even if the water be renewed three times during one steep.

The time of steeping, which varies according to the temperature and other circumstances, requiring in winter a longer and in summer a shorter period, is reckoned technically by the term "tide," each being of twelve hours' duration. In summer from forty to forty-eight hours is sufficient time for good grain. In winter it may extend over five and a half or six tides, from the time the liquor is put into the cistern to the time of letting, sixty-six or seventy-two hours; at others it will cease to swell much sooner, but, as a general rule, the grain is permitted to lie in the cistern until it will no longer swell, after which, the liquor being drawn off, it is left to drain for six hours before it is emptied into the couch. If now the skin, which is somewhat loosened, be partially removed from the kernel, and the two ends are slightly pressed, the latter will be seen to be partly separated.

Any practical farmer would say that the worst way to make seed germinate and grow well is to drown it; but this is exactly what is done, and by law obliged to be done, by the maltster. In the fifty hours during which the barley is in steep the following changes take place:—

In the first place the grain swells much as it would in the soil; it absorbs water, which dissolves some of the albuminous matter, some of the so-called diastase, and owing to the solution of the albuminous bodies a change is set up, and a degradation or a breaking down of the albuminous matter goes on; and following on that degradation there is at the same time a conversion of the insoluble starch (which is of no use to the young plant, for it requires soluble food) into soluble dextrine and also glucose.

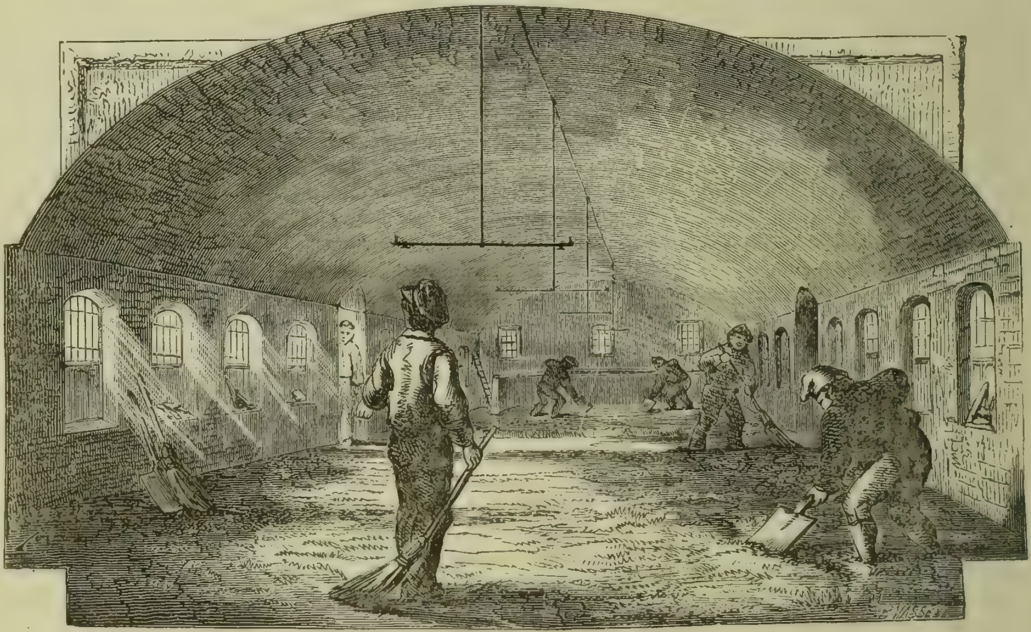
As time goes on the water in the steep gradually dissolves out, not only the colouring matter from the husk, but also some of the soluble albuminous matters, and at the same time some of the soluble dextrine and glucose which is formed. The water becomes darker and darker in colour, it froths when poured from one vessel to another, and then is set up a slow putrefactive fermentation, producing in warm weather a most unpleasant smell.

In Bavaria steeping is carried to a still greater extent, for the maltster soaks it for at least three days, renewing the water constantly.

In Bohemia the plan pursued appears to be more scientific. The grain is steeped for twenty hours, taken out, allowed to dry, and after about twenty-four hours returned to the steeping cistern for from six to eight hours, according to the season.

The Couch.—The water being drawn off, and a fresh quantity occasionally passed through, to separate the grain from any slimy matter which may have been generated, it is laid upon the stone flag-floor of the couch in square heaps, from 12 to 16 inches in depth, and left in that position for twenty-four hours.

Fig. 1.



The bulk of the grain being greatest at this time, the revenue officers may, if they think fit, gauge it. The surface of the barley is now so entirely freed from moisture that it does not feel damp. By degrees, however, it becomes warm, its temperature being 10° Fahr. (5°·5 C.), above that of the atmosphere, and it gives out an agreeably fruity smell. If at this time the hand is thrust into the heap it becomes bedewed with moisture. At this sweating stage the germination commences; the fibrils of the radicle shoot forth from the tip of every grain, and a white elevation appears, which soon separates into three or more rapidly increasing radicles. About a day after this appearance, the plumula (acrospire of the maltster), peeps forth from the same point, and would proceed under the husk until it appeared at the other end of the seed as a green leaflet; but this never happens in malting, as the operation is finished before it takes place.

About ninety-six hours after the barley has been taken out of the steep the heat is the greatest, consequently the radicles increase in length with great rapidity, and their growth must be checked by artificial means. The time at which this should be done constitutes the chief art of the maltster.

The barley must be spread out thinner upon the floor, and turned several times a-day—as shown in Fig. 1—the interior being always brought to the surface by the spades of the workmen. The depth, originally 15 or 16 inches, is slightly lessened at each turning, till it is at last not more than 3 or 4 inches. Two spadings per day are generally requisite. At this period of spreading or flooring the temperature in England is about 62° Fahr. (16°·6 C.), but in Scotland only 56° or 57° Fahr. (13°·3 and 13°·8 C.)

The rudiments of the stem, or the plumula, sprout forth about a day after the appearance of the radicles.

To a limited extent the barley absorbs oxygen and emits carbonic acid, just as animals do in breathing; the grain loses from 1½ to 3 per cent. of its weight upon the malt floor, a portion of this being due to waste particles. As the acrospire creeps along the surface of the seed the constituents undergo a remarkable alteration. The gluten and mucilage in a great degree disappear, the colour becomes whiter, and the substance so friable that it crumbles into meal between the fingers. This is the great object of malting, which is accomplished when the acrospire has reached the end of the seed. At this period the growth must be completely stopped. The duration of the germination in England may be reckoned fourteen days; but in Scotland eighteen or even twenty-one are required, owing to the lower temperature of the couch.

The shorter the period within these limits the better, as there will be a quicker return of capital, and a superior malt produced. In dry weather it is sometimes necessary to moisten the barley upon the couch.

If an offensive odour, somewhat resembling that of rotten apples, be observed to arise from the couch, it is a bad omen, showing that either the quality of the barley was inferior, or that, through carelessness, the workmen have crushed a number of the grains in turning.

On this account, when the weather causes too quick germination, it is better to arrest it by spreading the heap out thinner than by turning it too often.

Comparing different samples of barley, it will be found that the best grain develops the acrospire quicker than the radicles, and thus gives rise to a greater production of the saccharine principle: this conversion advances and keeps pace with the growth of the acrospire, so that the portion of the grain to which it has not reached remains in its unaltered starchy state. The conversion is never complete till the acrospire has attained the opposite end of the grain to that from which it sprung; hence one portion of the corn may be "sugary," while the other is still tasteless. If the grain was allowed to vegetate still longer, the future stem would become visibly green, it would shoot forth rapidly, the interior of the grain would appear milky, a complete exhaustion of all its useful constituents would ensue, and nothing but husk remain.

In France the brewers, who are generally their own maltsters, seldom leave the barley on the couch longer than eight or ten days, which is too short a period, even when allowance is made for the extra warmth of the climate; hence the wort made from the same quantity of malt is much inferior to that of the English brewer.

At the conclusion of the germination the radicles have become once and a half as long as the barley, and are so contorted that the corns hook one into another, but the acrospire is only just beginning to make its appearance.

A moderate temperature is best fitted for malting; it cannot, therefore, be well carried on in the heat of summer or the cold of winter.

Malt floors should be placed in substantial thick-walled buildings, the more concealed from the rays of the sun the better, so that the temperature of the interior may be uniformly from 59° to 60° Fahr. (15°·0 to 15°·5 C.) They are considered by some maltsters to be better when slightly sunk beneath the surface of the ground, provided that the situation is dry.

During germination portions of the glutinous constituent of the grain disappear, which it is conjectured have passed into the radicles, while a portion of the starch is converted into sugar and mucilage. The change is similar to that which starch undergoes when dissolved in water, and digested at a heat of about 160° Fahr. (71°·1 C.) with a little gluten. The thick paste becomes by degrees liquid, transparent, and sweetish to the taste, the solution containing sugar and gum mixed with some unaltered starch. At the same time the gluten undergoes a change and becomes acid, so that only a certain amount of starch can be thus modified by a quantity of gluten. By the artificial growth upon the malt floor the whole of the gluten and albumen is not decomposed, and only about one-half of the starch is changed into sugar; by a continuance of the germination the remainder would only assist the growth of the roots and stems; it is, however, nearly altogether converted into sugar in the brewer's operation of mashing.

If the grain is suffered to sprout in the couch it will never be even afterwards, as those corns which are sprouted will attract more than their proper share of moisture; moving and turning at proper intervals is intended to retard this and cause each corn to shoot almost simultaneously.

The Flooring.—In this operation the grain is turned inside out from the couch into the bed, which is made to occupy two or three times as much space as the former, according to the temperature. It may lie here for about six hours, observing in the interim whether the grains are commencing to shoot; or, if this is not the case, giving it a gentle turning, and spreading it out thinner, before the expiration of the period named. It may be laid all the width of the floor, and permitted to remain for another six hours, when all the healthy corns will have sprouted; it is then again thinned, and after this, while it is in full vigour, often turned. By this manipulation the root is kept short and bushy, and retains the moisture to the period of its withering, if the process be of sufficient duration, without sprinkling.

The root begins to fade about the eleventh or twelfth day.

If, on taking a handful of the grain from the floor, it smells faint, and the skin is glossy or wet, it requires turning. After this it will smell fresh, and the grain, instead of being glossy, will be dry. If the turning is omitted at the proper time the root will be of unequal length.

On the grain beginning to wither, it may be spread out thicker, to generate a little more warmth and to mellow it, still keeping it frequently turned, to prevent a glossy appearance, until the moisture is further expelled, and also to retard the progress of the acrospire.

The grain, when ready for drying, must easily rub to meal between the fingers, after being deprived of the skin.

Kiln-drying.—When the malt has become perceptibly dry to the hand upon the floor, it is taken to the kiln and hardened with artificial heat, to prevent all further growth, and enable it to be kept, without fear of change, for use.

The malt should be evenly spread upon the drying cloth or floor, in a layer varying from 3 to 10 inches in thickness, according to the kind of malt (pale, yellow, or brown) which is to be produced, and a heat of from 90° to 100° Fahr. (32°·2 to 37°·7 C.), steadily maintained, till the moisture is nearly all driven off. During this time the malt must be turned over, at first frequently, and towards the conclusion every third or fourth hour. When nearly dry, the temperature of the kiln should stand between 145° and 165° Fahr. (62°·7 to 73°·8 C.), and this heat must be maintained till the grain has acquired the desired colour.

The fire is now allowed to die out, and the malt is left on the kiln till sufficiently cool, this result being greatly accelerated by the stream of cold air rising up through the bars of the grate. Thoroughly dry brown malt may, however, by damping the fire, be taken hot off the plates, and cooled in some contiguous apartment. The kiln-drying should not be hurried; many persons allow the operation to occupy two days.

The temperature of the kiln should, in all cases, be most steadily maintained, and, when required, gradually elevated.

If the drying commences with too great a heat, the outer part of the grain hardens, and prevents the interior moisture from evaporating; should this be driven off by too high a temperature, the husk will, in all probability, split, and the farina become horny and very refractory in the mash.

It is preferable, therefore, to brown malt by a long-continued moderate heat, than to apply a strong one for a shorter period, which might carbonize a portion of the mucilaginous sugar, thereby deteriorating the value of the product.

In this manner the sweet very often changes to a bitter principle.

The malt, when prepared, must be kept in a dry loft, where it can be occasionally turned over till used.

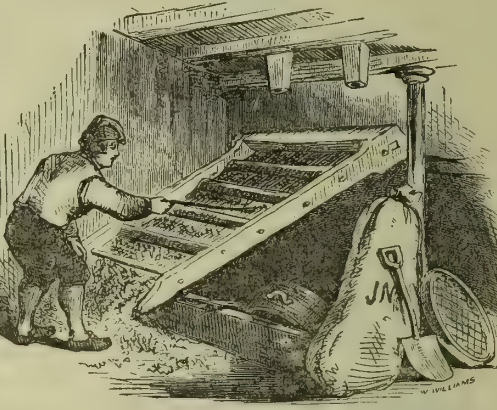
During the drying the roots and acrospire of the barley become brittle, and are, by the friction of turning, &c., broken off, and are afterwards separated by a fine wire sieve—Fig. 2. This operation is termed cleaning.

The *bulk* of good malt exceeds that of the barley from which it was fabricated by about 8 or 9 per cent.

Kiln-dried malt has a peculiar, agreeable, and faintly-burnt taste, probably from some empyreumatic oil generated in the husk, and which imparts its flavour to the beer, and at the same time it assists in preserving it. The skilful preparation of the malt, therefore, necessarily exercises a very great influence on the worts which are prepared from it. If the germination be pushed too far, a portion of the valuable matter is wasted, while, if it is not carried on sufficiently long, the malt will be too raw, and much of its starch will remain insoluble; if it is too highly kiln-dried, a portion of its sugar will become caramelized and bitter; and if the sweating was irregular or imperfect, much of the barley will be lumpy and useless.

The grains of good malt are round and full, break freely between the teeth, have a sweetish taste, an agreeable smell, and are full of soft flour. They give no unpleasant taste on being masticated; are not hard, but will give a free white streak, like chalk, when drawn across the fibres of wood; and lastly, will swim on water, which is not the case with unmalted barley.

Fig. 2.



Malt-kiln.—The construction of a well-contrived malt-kiln is shown in Figs. 3, 4, 5, and 6, the first being the ground plan; the second, a vertical section; the third, a horizontal, and the fourth, a vertical section in the line of the malt plates. The same letters in each of the figures are indicative of the same parts of the kiln.

In the middle, upon a wall of brickwork 4 feet high, is supported a cast-iron cupola-shaped oven, and beneath it are the grate and ash-pit. The smoke escapes through two equidistant pipes into the chimney. *a* is the grate, 9 inches below the sole of the oven, *b*; *c c c c*, are four strong 9-inch pillars of brickwork bearing the stone lintel, *m*; *d d d d d d*, are similar supports for the girder and joists, upon which are laid perforated plates; *e* indicates a vaulted arch on each of the four sides of the kiln; *f* is a space between the kiln and the side arch, allowing of the inspection and cleaning of the kiln; *g g*, walls, on which the arches rest, on each side of the kiln; *h*, the ash-pit; *k* is the furnace-door; and *l l* are junction pieces connecting the pipes, *r r*, with the kiln.

These smoke-draughts rest about 3 feet from the walls, and a similar distance from the malt-plates, upon iron supports secured to the arches. They are indicated in the vertical section—Fig. 4—by the letters *u u*; at *s s*—Fig. 6—they enter the chimney, to which is supplied two register or damper plates, intended to regulate the draught. These registers are represented by *t t*; the lintel, *m*—Fig. 4—is intended to cause the heat to spread laterally, instead of ascending in one mass in the middle, and prevents any combustible particles from falling upon the iron cupola; *n n* are main girders of iron supporting the joists, *o o*, of the same material, upon which the perforated plates, *p*, lie; *q* is a vapour pipe in the middle of the roof, allowing the steam of the drying malt to escape.

Fig. 3.

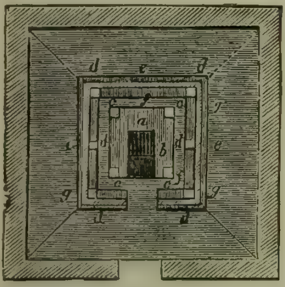


Fig. 4.

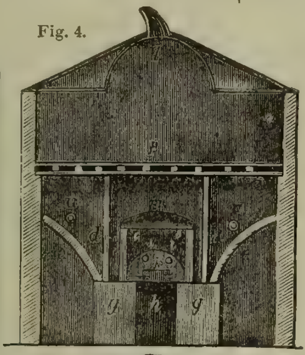


Fig. 5.

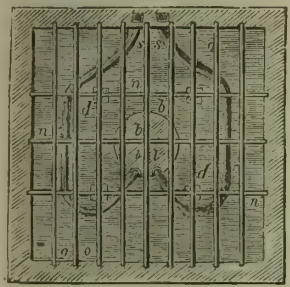
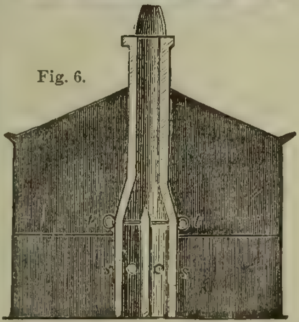


Fig. 6.



This kiln may be heated either with coal, coke, or wood. The size is about 20 feet square, but it may either be proportionally enlarged or diminished, as seems advisable. The perforated floor should be large enough for the contents of one couch or steep to be spread out upon.

It can be heated by means of steam pipes, laid irregularly, or in parallel lines under it, or a wire-gauze web might be extended upon such pipes. This steam apparatus might, without danger, be supported by joists of timber. For drying the pale malt of the brewers, this plan is well adapted.

Dr. C. Graham states that in Belgium they put a stop to germination, as soon as it has got far enough, by the process of drying simply in air, and so in some cases do the North Germans. Weiss beer is made with air-dried malt. It has to English taste a very raw, uncooked sort of flavour; but not only in Berlin, but also in Magdeburg and elsewhere, people are excessively fond of it. It is made not only from air-dried malt, but sometimes from a mixture of air-dried malt and raw grain. The worst characteristic of it is that it does not keep well, and that it has none of that pleasant empyreumatic flavour which kiln-dried malt has. The beer produced from kiln-dried malt has just the same advantage over air-dried malt which a cooked potato has over a raw one.

As regards the action of heat upon the starchy, saccharine, and albuminous substances contained in the barley, if they be dry, a higher temperature is required to produce as much decomposition as is produced by a low temperature when moisture is present. It therefore follows that, in order to apply the artificial drying which is done in a kiln, the great bulk of moisture which is there, and which still remains there in the English system, ought previously as much as possible to be got rid of. This may be readily done by imitating some of the Continental maltsters who, after the germination has gone on far enough, place their malt on the upper floors, where it is exposed to a current of air passing over it. In that way the rootlet is rapidly withered, the germination stopped, and the grain or malt is rapidly dried. The Germans, after having put it on the floor, place it on an upper kiln at a temperature of about 100° Fahr. (37°·7 C.), and after it has remained there for about five hours, it is let down to a lower kiln at a temperature of about 160° to 167° Fahr. (71°·1 to 75° C.). Now, as before remarked, too sudden a heat produces hardening or what is called vitrifaction of the starchy or dextrine matter; on the other hand, a too low heat leaves the grain with moisture, and still very liable to absorb more, and containing a larger quantity of the destructive albuminous constituents, and less of the empyreumatic bodies.

As regards colour, if the malt is previously dried, a perfectly pale malt is obtained at a temperature of 145° to 150° Fahr. (62°·7 to 65°·5 C.). Of course, if to obtain amber or brown, it must be heated somewhat more. High-coloured malts have some advantage over pale-coloured. In the first place there is more dextrine produced, and in the second place more of the albuminous matters are rendered insoluble; lastly, there is more colour. When this is carried to a very high point, as is done in the manufacture of English porter, this is a matter of great importance, because it not only fulfils the conditions which the consumer requires, but by the advantages which the high colour presents, it, like charity, covers a multitude of sins. It is much more easy to work with a high-dried malt than with a very low-dried malt.

With respect to the thickness on the floor, Dr. Graham considers that in England it is far too great, being 12 and 18 inches thick, and sometimes even thicker still, and very wet. Now, barley kept in a very moist condition at 80°, 90°, and

100° Fahr. (26°·6, 32°·2 and 37°·7 C.), is in the condition necessary for the production of acid. He states that he never yet examined a sample of malt dried in that way which did not contain acid. He says—"Not only do I consider the thickness too great, but I even consider one kiln floor to be bad. In the first place, because the malt must be thicker, and because it is more difficult to regulate the heat than when there are two, and also because it is more difficult to get rid of the moisture; then lastly, because more time is required, and instead of the process being finished in a few hours, it takes some three or four days, sometimes even more. The advantages which two floors present are very evident. The malt may be thinner, the temperature may be regulated in two distinct stages by having a lower temperature in the higher floor, and a higher temperature in the lower one."

Malt Testing.—The examination of malt may be divided into two main classes; first of all, the physical examination; and secondly, the chemical.

Dr. Graham says:—It is a good plan to take 100 distinct seeds, and examine how far the plumule has grown, and if there is more than 5 per cent. which have projected, it is an indication that there has been a waste of material. If, on the other hand, more than 5 per cent. have been inefficiently germinated, that is also rather an approach to mixing raw grain with malt. There should be no vitrified appearance when broken, because the vitrified appearance is either due to too sudden heating, or to the barley having been grown upon too rich a soil, being too rich in albumen, or to mixed seed having been employed which did not germinate equally. If 100 seeds are taken (this is an old German rule which has been long known in England also), thrown into water, and just stirred about; if the malt be good, not more than five should sink. If more than 5 per cent. sink, then the malt is not good.

To effect the chemical examination of malt, take 50 grms. of malt, powder them, and place them in a beaker, and add to the powdered malt 300 cubic centimètres (that is 300 grammes) of cold water, and then gradually heat that up through a period of half-an-hour to 140° to 145° Fahr. (60° to 62°·7 C.). After it has reached that temperature the malt should be kept so for one hour, and then should be heated somewhat rapidly, so that at the end of the next half-hour, making two hours altogether, it may have come to the boiling point. Finally, it should boil for five minutes. After that filter and wash it with boiling water. This should be done until such time as the half-litre, which is 500 cubic centimètres, is filled up to the mark indicated on every half-litre flask.

With this solution the different chemical tests can be proceeded with, bearing in mind that this solution contains an extract of 50 grms. in 500 grms. of water, therefore 10 per cent.

The insoluble matter should then be placed in an air bath, with a lamp underneath, where it should be heated for two and a half or three hours to a temperature of 230° Fahr. (110° C.), and weighed. This will give the percentage of "draff," *i.e.*, the amount of insoluble matter.

The process for the determination of the glucose, or grape sugar, and dextrine, is as follows:—From the solution, containing 50 grms. of extract to 500 grms. of water, 50 cubic centimètres are taken and put into a 500 cubic centimètre flask, then 450 cubic centimètres of water are added, making altogether 500 cubic centimètres of liquid, containing 50 cubic centimètres of concentrated solution. Fehling's solution is next made by dissolving 34·64 grms. of sulphate of copper in 200 cubic centimètres of water. Then add to that 173 grms. of pure Rochelle salt (double tartrate of sodium and potassium), dissolve and add 480 cubic centimètres of caustic soda solution, at a specific gravity of 1·14; and lastly, make the whole up to one litre with water. When using this solution take 10 c.c., dilute with 40 c.c. of water, and boil for some minutes. If a precipitate forms the copper solution is unfit for use.

Ten cubic centimètres of Fehling's copper solution are equal to ·05 grm. of grape sugar; that is to say, the ·05 grm. of grape sugar reduces the oxide of copper in 10 cubic centimètres of the solution down to the state of suboxide, a precipitate is produced, and the blue colour of the liquid is destroyed.

The dextrine is determined by taking 25 cubic centimètres of the concentrated solution of malt, diluting it down to 200, and adding 4 cubic centimètres of oil of vitriol, and then boiling the whole for two hours to convert the dextrine into glucose; it is then made up to 250 cubic centimètres, and when treated as above with Fehling's solution, gives the total amount of glucose and dextrine.

Practical brewers take the specific gravity when the wort is cooled down to a proper temperature, and look at the already calculated tables; but, unfortunately, that method gives very inaccurate results, because the density is due to many things besides dextrine and sugar. A much more accurate way is to make the solution, as above mentioned, of 50 grms. of malt made up to 500 with water, then to take a known quantity, 25 cubic centimètres, which will contain 2½ grms., evaporate to dryness, then dry it at 220° to 230° Fahr. (104°·4 to 110° C.) for one hour. This will give the total solid extract. Weigh the residue, and deduct the weight of the vessel, the remainder, multiplied by forty, will give the percentage of solid extract.

A simple way of determining the grape sugar and dextrine is to take 25 cubic centimètres of the extract, and add to it about 150 cubic centimètres of strong spirits of wine; this precipitates the whole of the dextrine, and most of the albumen. It will not filter in this condition, the precipitate being so fine, but after shaking it with animal charcoal for a few minutes it will filter perfectly well; then transfer it into a glass or platinum vessel and evaporate off the alcohol. The more economical method would be to distil it off in a flask, and then afterwards wash out the contents of the flask much in the same way as in determining the original gravity of beer. If what is left in the platinum vessel is evaporated to dryness, and heated for one or two hours to about 220° to 230 Fahr. (104°·4 to 110° C.), the weight or percentage of grape sugar in the extract is obtained. Now, deducting the percentage of grape sugar thus obtained from the total, gives the amount of dextrine. There must, however, be this correction made, that the total extract is not altogether grape sugar and dextrine. Dr. GRAHAM has found by repeated experiment that there is, roughly speaking, about 2 per cent. of albuminous matters and salts, so that it is necessary to deduct an additional 2 per cent. to obtain the percentage of dextrine. Of course this process is not so accurate as the more scientific but complicated one.

The acidity of the malt solution may be determined by a standard solution of soda or ammonia. The acidity of a cold infusion of the malt should be likewise ascertained. THOMAS POOLEY, who has had very great experience in testing malts, states that if there be much difference between the amount in the cold infusion and in the hot, the malt is likely in the after processes to keep on producing more and more lactic acid. As to the maximum amount which ought to be permitted, about 0·2 to 0·3 per cent. only should be allowed.

The amount of water in malt is determined by crushing some of the malt, say 5 or 10 grains, and drying it at 230° Fahr. (110° C.).

MALTING IN MUNICH.—The barley is steeped till the acrospire seems to be quickened, a circumstance indicated by a swelling at the end of the grain which was attached to the footstalk, as also when, on pressing a pile between two fingers against the thumb nail, a slight projection of the embryo is perceptible. As long, however, as the seed-germ sticks too firm to the husk, it has not been steeped enough for exposure on the underground malt-floor. Nor can deficient steeping be safely made up for afterwards by sprinkling the malt-couch with a watering-can, which is apt to render the malting irregular. The steep-water should be changed repeatedly, according to the degree of foulness and hardness of the barley: first, six hours after immersion, having previously stirred the whole mass several times; afterwards, in winter, every twenty-four, but in summer every twelve hours. It loses none of its substance in this way, whatever vulgar prejudice may think to the contrary. After letting off the last water from the stone cistern, the Bavarians leave the barley to drain in it during four or six hours. It is now taken out and laid on the couch floor in a square heap, 8 or 10 inches high, and it is dexterously turned over, morning and evening, so as to throw the middle portion upon the top and bottom of the new-made couch. When the acrospire has become as long as the grain itself, the malt is carried to the "withering" or drying floor, in the open air, where it is exposed in dry weather during eight to fourteen days, being daily turned over three times with a winnowing shovel. It is next dried on a well-constructed cylinder, or flue-heated malt-kiln, at a gentle clear heat, without allowing it to brown in the slightest degree, while it becomes friable and turns into a fine white meal. Smoked malt is entirely rejected by the best Bavarian brewers. Their malt is dried on a series of wove-wire horizontal shelves, placed over each other; up through the interstices or perforations of which streams of air, heated only to 122° Fahr. (50° C.), rise from the surfaces of rows of hot sheet-iron pipe flues, arranged a little way below the shelves. Into these pipes the smoke and burned air of a little furnace on the ground are admitted. The whole is inclosed in a vaulted chamber, from the top of which a large wooden pipe issues, for conveying away the steam from the drying malt. Each charge may be completely desiccated on this kiln in from eighteen to twenty-four hours by a gentle uniform heat, which does not injure the diastase or discolour the farina.

COMPOSITION OF RAW AND MALTED BARLEY.—PROUST affirms that barley contains a peculiar proximate principle, which, from the Latin name of the grain, he denominated *hordein.* He describes it as a yellow, granular, woody powder, in appearance very much resembling sawdust, and says that it disappears in great quantity during malting, being resolved chiefly into starch and sugar. It has since been found to be a mixture of starch, cellular tissue, and a nitrogenous body.

PROUST states that barley meal contains—

Hordein,	55·0
Starch,	32 0
Sugar,	5·0
	92·0

Dr. T. THOMSON gives no hordein, but—

Starch,	88·0
Sugar,	4·0
	92·0

The analyses of PROUST and THOMSON agree exactly, only one takes the 88·0 to be solely starch, while the other assumes it to be a peculiar principle and that body.

The sugar found in the barley was, no doubt, the result of the action of some of the reagents employed by the above chemists on the starch.

THOMSON looked upon the hordein as merely starch in a peculiar state, somewhat similar to the fibrous matter of potatoes, malting having the effect of converting it into starch and sugar.

This peculiar substance, hordein, is now considered to be formed by kneading barley-meal in water; its presence in so great a quantity as 50 per cent., its being woody and insoluble in both cold and boiling water, its disappearance during the malting, and the increase of gum, sugar, and starch in consequence, are properties incompatible with its being any component part of the grain.

Hordein seems to be an allotropic modification of starch. It is very probable that this state is owing to some impurity or extraneous matter, and that, could this be removed, it would be found to consist of starch only.

Annexed is the mean of ten analyses of barley performed by HERMBSTADT:—

	Centesimally represented.
Water,	10·48
Husk,	11·56
Gluten,	4·92
Albumen,	0·35
Starch,	60·50
Sugar,	4·66
Gum,	4·51
Oil,	0·35
Soluble phosphates, &c.,	0·36
Loss,	2·31
	100·00

The following analyses are by OUDEMANS:—

COMPOSITION OF BARLEY (DRIED).

Starch,	65·7
Dextrine,	5·5
Gluten, insoluble in water, soluble in alcohol,	0·3
Soluble albuminous bodies (coagulable by heat),	0·3
" " (not coagulable),	1·9
Albuminous bodies (insoluble in water or in alcohol),	9·3
Fatty substances,	2·5
Cellulose,	9·4
Ash,	3·1
Water.	0·0
Loss, &c.,	2·0
	100·0

COMPOSITION OF BARLEY AND MALT.

	BARLEY.	MALT.		
	Air dried.	Air dried.	Kiln-dried (pale).	Kiln-dried (amber).
Produce of torrefaction,	0·0	0·0	7·8	14·0
Dextrine,	5·6	8·0	6·6	10·2
Starch,	67·0	58·1	58·6	47·6
Sugar,	0·0	0·5	0·7	0·9
Cellulose,	9·6	14·4	10·8	11·5
Albuminous substances,	12·1	13·6	10·4	10·5
Fatty ditto.,	2·6	2·2	2·4	2·6
Ash, &c.,	3·1	3·2	2·7	2·7
	100·0	100·0	100·0	100·0

ALBUMINOUS COMPOUNDS IN BARLEY AND MALT.

	Barley.		Malt.
Gluten, soluble in alcohol,	0·28	..	0·24
Albuminous substances, coagulable by heat,	0·28	..	0·45
Do., not coagulable,	1·55	..	2·08
Insoluble albumen,	7·59	..	6·23
	9·70		9·10

CONSTITUENTS OF BARLEY.

	FEHLING AND FAISST.		POLSON.	POGGIALE.
	Five Samples Wurtemburg.	Two Samples Wurtemburg, without husk.	New Scotch.	Mean of Analysis.
Water,	13·91 — 15·60	12·97 — 14·33	12	13·7
Starch,	79·53 — 81·08	78·60 — 82·92	52.7	74·5
Fat,			2·6	0·2
Cellulose,	2·58 — 4·55	1·26 — 1·84	11·5	3·4
Sugar,	—	—	4·2	—
Nitrogenous bodies,	12·01 — 15·73	13·71 — 17·46	13·2	7·8
Nitrogen,	—	—	—	—
Ash,	2·62 — 3·04	2·10 — 2·11	2·8	0·3
Phosphoric acid (P_2O_5),	0·95 — 1·13	0·99 — 1·09	—	—
Silica (SiO_2),	1·51 — 0·86	0·13 — 0·17	—	—

The amount of inorganic matter in different specimens of barley varies very considerably. This might be anticipated from the fact, now generally admitted, that the nitrogenized or nutritive principles of grain or seeds bear a relation to the phosphoric acid present; thus, if the quantity of the latter be small, it follows that the amount of nitrogen is proportionally deficient, and the nutritive effect of the grain will be comparatively low in the scale. The solubility of the albuminous matters, and therefore their capability of being carried into plants, appears to depend on the presence of the phosphates.

Thomson gives the following as the composition of the ash of barley and malt:—

	Centesimally represented. R. D. Thomson. Barley.		Malt.
Potash,	16·00	....	14·54
Soda,	8·86	....	6·08
Lime,	3·23	....	3·89
Magnesia,	4·30	....	9·82
Ferric oxide,	0·83	....	1·59
Phosphoric acid (P_2O_5),	36·80	....	35·34
Sulphuric acid (SO_3),	0·16	....	—
Chlorine,	0·15	....	trace.
Silica,	29·67	....	28·74
	100·00		100·00

COMPOSITION OF THE ASH OF BARLEY (WAY AND OGSTON.)

	Chevalier Barley.					Moldavian.			Long-eared Nottingham or Sandy Soil.
		Clay Soil.	Sandy Soil.	Loamy Soil.	Chalky Soil.		Clay Soil.	Sandy Soil.	
Potash (K_2O),	26·83	22·43	24·97	28·60	37·22	19·78	26·61	22·46	32·02
Soda (Na_2O),	—	1·42	0·51	—	—	0·89	1·26	4·93	1·21
Lime (Ca_2O),	3·62	1·96	2·97	2·97	2·92	4·20	1·26	1·88	3·39
Magnesia (Mg_2O),	4·78	10·00	8·00	6·90	7·63	8·15	9·32	8·47	10·99
Ferric oxide (Fe_4O_3),	1·54	0·87	0·84	1·46	trace.	0·93	0·24	0·10	0·15
Sulphuric acid (SO_3),	1·30	2·82	0·92	trace.	0·26	0·39	0·47	0·53	trace.
Silica (SiO_2),	29·79	22·25	22·08	18·47	17·27	27·66	30·35	28·09	21·12
Carbonic acid (CO_2),	4·35	—	—	—	—	—	—	—	0·48
Phosphoric acid (P_2O_5),	25·32	37·67	38·26	38·78	30·76	37·99	30·08	32·92	29·92
Potassium chloride,	—	—	—	1·29	1·93	—	—	—	—
Sodium chloride,	2·47	0·56	1·44	1·59	2·01	trace.	0·41	0·61	0·72
	100·00	99·98	99·99	100·00	100·00	99·99	100·00	99·99	100·00
Ash in 100 parts of fresh barley,	2·32	2·65	2·47	2·28	2·39	2·28	2·55	2·07	2·20
Ash in 100 parts of dry barley,	2·03	2·30	2·15	2·07	2·13	2·03	2·31	1·79	1·99
Sulphur in 1000 parts of dry barley,	3·53	0·96	1·21	0·74	1·83	2·42	1·54	1·58	1·41

The ultimate constituents of a sample of barley, and of malt made from it, is given below, thus showing the alteration in the grain by malting:—

	Barley.			Malt.		
	Natural State.		At 212°.		Natural State.		At 212°.
Carbon, ...	41·64	..	46·11	..	42·44	..	43·93
Hydrogen, ..	6·02	..	6·65	..	6·64	..	7·00
Nitrogen,...	1·81	..	2·01	..	1·11	..	1·29
Oxygen,.....	37·66	..	41·06	..	43·08	..	46·51
Ash, ...	3·41	..	4·17	..	1·68	..	1·27
Water, ...	9·46	..	—	..	5·05	..	—
	100·00		100·00		100·00		100·00

The mean of a number of experiments relative to the loss which barley sustains by malting, indicated 19 per cent.

The whole of the loss is not solid matter, as barley uncrushed contains 13·1 per cent. of water; and malt, in the same condition, 7·06 per cent.

There thus remain 13 per cent. of solid loss.

Muspratt found that a mean of several trials gave for the ash of barley 3·0; and for that of malt, 2·52 per cent. Now, as 100 of the former are equal to 80 of the latter, the quantity of ash which malt should contain is 2·42, if the loss of organic and inorganic matter was equable, which it is observed to be, almost approximately, from this experiment; for the relation of the ash which has disappeared, or 0·48 per cent., bears almost the some proportion to the organic matter removed, as the total quantity of ash in barley does to the whole of the organic matter in that grain. Thus, barley contains 84 per cent of *dry* organic matter and 3 per cent. of ash, while malt has lost 0·48 per cent. of ash, and 12·52 of organic matter, and by calculation—

As 3 : 0·48 :: 84 : 13·4.

A remarkable coincidence, as if proving that water is incapable of removing the inorganic portion of plants, until the organic matter has undergone such a change as to allow the ash to separate.

From the above, the loss sustained by barley in malting may be stated thus:—

Water, ...	6·00
Saline matter, ...	0·48
Organic matter, ...	12·52
	19·00

Water.—Good water in a brewery is of the utmost importance, but what should constitute the composition of a good water is with brewers a much debated question.

Perhaps nothing in nature is more variable in character than this apparently simple fluid, which is not the *aqua pura* which it seems, and which it was formerly believed to be, but a heterogeneous mixture of alkaline and metallic salts, acids, gases, and occasionally even animal and vegetable matter, some of which are held in chemical union, and others in mechanical suspension. Pure water, or hydrogen oxide (H_2O), is only obtained by art.

Some brewers prefer soft and others hard water, whilst a few are quite indifferent on this point.

Were the density of the worts, and the value of cold water for refrigeration and other purposes, alone to be considered, there would be little hesitation in their choice; but the constituents of the water are of importance, accordingly as the beer to be brewed is to be drunk speedily, or is intended to be kept for a prolonged period; therefore, though a brewer already established can seldom choose a different spring or stream, the case is much altered when the site of a new brewhouse is to be selected.

Water entirely free from saline matter, or which holds it only in very small quantity, is unfit for brewing.

In England nearly every one at all acquainted with brewing holds that water which contains a large quantity of gypsum (sulphate of lime), earthy carbonates, and no organic matter, is best adapted for this purpose.

Many reasons are given for this. Hassall says:—During ebullition the excess of carbonic acid in the water, by which the carbonates of lime and magnesia are retained in solution, is expelled, and those salts are precipitated. Again, the alkaline phosphates present in malt have the power of converting sulphate of lime into phosphate, which is thrown down; an alkaline sulphate, which is soluble, being synchronously formed. The greater part of the phosphate of lime produced is redissolved in the acid generated during the fermentation; consequently the water, from being hard, thus becomes comparatively soft, and in this state is well suited for extracting the active properties of the malt and hops.

This is entirely speculative, and is not based on experiment; nevertheless, the theory is ingenious.

Another advantage claimed for the use of hard water is, that more saccharine matter can be left in the beer, by which its fulness and flavour will be increased, and its liability to become acid prevented.

German brewers, however, consider the presence of mineral salts in the water as uniformly bad, and Mülder has pointed out that the action of these salts in producing hard water in the mashing process, is very much the same as that which occurs when peas or beans are boiled in hard water, as compared with the result when they are boiled in soft water. In the case of vegetables, hard water produces a leathery insoluble toughness in the skin, and prevents it bursting; whereas the soft water allows the contents to come out more easily. Mülder therefore says:—"I object to keeping the albuminous matter insoluble; I want to get all that is possible out of the malt."

English brewers, on the other hand, working on a different system, and brewing beers which are not intended to be drunk for some months afterwards, are justly afraid of having too large a quantity of albuminous matter in the solution from the mash, because these albuminous constituents are the most powerful agents in continuing fermentation beyond the point at which they wish it to cease.

Water loaded with organic matter, like that of the Thames, is a decided loss to the brewer, as the vegetable and animal remains are decomposed during brewing, and carry with them some portion of the strength of the wort, besides rendering it and the beer liable to spoil.

Messrs. ALLSOPP & SONS, Messrs. BASS & Co., Messrs. SALT & Co., and other eminent Burton brewers, have long been celebrated for the quality of their beer, and many conjectures have been made to account for the excellence and superiority of the article brewed in that locality. Their success has arisen in a great measure from the quality of the water they use. The water from the Burton springs is very hard, and is remarkable for its quantity of earthy and alkaline sulphates and carbonates, and, *à priori*, it would be considered but ill adapted for the purposes of the brewer. This, however, as long experience has shown, is not the case.

The following is an analysis by Dr. BÖTTINGER, brewer to Messrs. ALLSOPP & SONS, of the water used in that celebrated establishment:—

	Amount of Ingredients in the imper. gallon. Represented in Grains.
Chloride of sodium,	10·12
Sulphate of potash,	7·65
Sulphate of lime,	18·96
Sulphate of magnesia,	9·95
Carbonate of lime,	15·51
Carbonate of magnesia,	1·70
Carbonate of iron,	0·60
Silica,	0·79
	65·28

Some years ago COOPER analyzed water taken from a well at the brewery of Messrs. BASS & Co. He found—

Carbonate of lime,	9·93
Sulphate of lime,	54·40
Chloride of calcium,	13·28
Sulphate of magnesia,	0·83
	78·44

The whole of the water used at Burton for brewing is spring water, and not that of the river Trent, as has been erroneously supposed.

On boiling it deposits a large amount of carbonates of calcium and magnesium, besides a small quantity of calcium sulphate; a little iron, which it contains, becomes also eliminated.

The geological formation from which this water appears to emanate is New Red Sandstone; in the immediate vicinity of Burton there are large strata of new red marl, with a considerable amount of gypsum.

The water employed at the brewery of Messrs. TETLEY & SON, Leeds, bears some analogy to the preceding, as will be seen on referring to the annexed analysis by MUSPRATT.

	Per Gallon.	
Carbonate of lime, Carbonate of magnesia,	19·78	grains.
Carbonate of the protoxide of iron (Ferrous carbonate),	0·93	"
Sulphate of lime,	4·97	"
Sulphate of soda,	13·09	"
Sulphate of magnesia,	9·73	"
Chloride of sodium,	7·11	"
Chloride of magnesium,	4·74	"
Loss,	1·72	"
	62·07	

The three waters contain a varying amount of carbonic acid in the uncombined state, keeping the carbonates in solution.

MUSPRATT suggests that when brewers in certain districts are compelled to use soft water, or that which runs off moors or fens, for want of better, they should impregnate them at second hand with gypsum, or with such limestones as are easily procurable. He states that this plan has been found most serviceable, and the ale obtained from such artificial water has nearly equalled the renowned product of Burton.

The imitation of the Burton water can be rendered more complete by adding salt as well as gypsum to any soft water.

Dr. GRAHAM thinks that though the sulphate of lime has certainly very much to do with the properties of the Burton water; nevertheless something is also due to the chlorides of sodium, magnesium, calcium, &c., likewise present. Practical brewers are aware that in many cases when the water contains a certain quantity of chlorides, the ale produced is as much to be depended on for its long keeping qualities as that made with water containing sulphate of lime.

HOPS.—The wort, as prepared from malt alone, is unpalatable. To make it potable, and insure the permanence of its flavour, it has been found necessary to make some addition to it previous to fermentation. This effect is best produced by means of hops.

Hops are the strobiles or catkins of *humulus lupulus*, a diœcious plant belonging to the natural order Urticaceæ, the culture of which was first introduced into England from Flanders in the reign of HENRY VIII.

The various parts of the hop are scales, nuts, and lupulinic grains or glands. The scales are the enlarged and persistent bracts enclosing the nuts, which are small, hard, nearly globular, and covered with aromatic superficial glands, commonly termed "yellow powder" or "lupulin." These form the most important part of the strobiles.

Dry hops ought to yield about one-sixth of these grains. They are usually mingled with silica.

PEREIRA says they are rounded, of a cellular texture, golden-yellow coloured, somewhat transparent, and are sessile, or nearly so.

The common centre around which the cells are arranged has been denominated the *hilum*. They lose their spherical form by drying, and, when placed in water, give out an immense number of minute globules. Under different circumstances they become ruptured, allowing an inner envelope to escape.

The scales and lupulinic grains have been analyzed by PAYEN, CHEVALLIER, and PELLETAN, with the following results:—

LUPULINIC GRAINS.

	Centesimally represented
Volatile oil,	2·00
Bitter principle—lupulin,	10·30
Resin,	55·00
Lignin,	32·00
Fatty, astringent, and gummy matters, malic and carbonic acids, salts, as malate of lime, acetate of ammonia, chloride of potassium, sulphate of potassa, &c.,	traces.
Loss,	·70
	100·00

The scales were found to consist of astringent matter, inert colouring matter, chlorophyl, gum, lignin, and salts of potassium, calcium, and ammonium, containing acetic, hydrochloric, sulphuric, nitric, and other acids.

The scales usually have lupulinic matter adhering, from which it is almost impossible to free them.

Dr. Yves also examined lupulin, and obtained—

	Centesimally represented.
Tannin,	4·16
Extractive,	8·33
Bitter principle,	9·16
Wax,	10·00
Resin,	30·00
Lignin,	38·33
Loss,	·02
	100·00

Oil of Hops.—A volatile oil is procured by distilling the lupulinic grains or the hops with water. It has a yellowish colour, an acrid taste, and its odour is similar to that of the strobiles. It is partially soluble in water, but more so in alcohol and ether. It has a specific gravity of 0·910, becomes resinified by keeping, and is said to have a narcotic influence on the system. The water which distils over with the oil contains acetate of ammonia.

Rudolph Wagner investigated oil of hops. He distilled the oil from fresh hops with water. It constituted about 8 per cent. of the air-dried flowers. It possessed a clear brownish-yellow colour, and had a strong odour of hops, and a slightly bitter taste analogous to thyme. Its specific gravity was 0·908 at 61° Fahr. (16°·1 C.). It scarcely reddened litmus paper, and was very sparingly soluble in water, requiring more than 600 times its weight for solution. It contained no sulphur. The oil, rendered anhydrous by distillation over fused chloride of calcium, partly evaporates at a temperature below the boiling point of water. It begins to boil at 257° Fahr. (125° C.), rising to 347° Fahr. (175° C.), where it remains stationary for some time, and at which temperature nearly one-sixth of the clear oil distils over. The portion passing over between 347° Fahr. and 437° Fahr. (175° C. and 225° C.), and constituting one-half of the oil, was also very clear, and had the odour of the crude oil. That which passed over between 437° Fahr. and 455° Fahr. (225° C. to 235° C.) was of a yellow colour. The residue in the retort, about one-sixth of the quantity submitted to distillation, was brownish, and like turpentine. It is therefore evident that oil of hops is a mixture of oils. The crude oil does not give, with ammoniacal silver solution, a metallic mirror. It is therefore not an aldehyde. When mixed with alcohol-potassa, it becomes brown, and when distilled affords alcohol and an oil having the odour of rosemary.

After the greatest part of the oil and spirit has distilled over a violent action takes place, hydrogen is evolved, and potassium carbonate, mixed with a potassium salt of a volatile fatty acid, remains: the latter, when decomposed with diluted sulphuric acid, evolves an odour indicating the presence of caprylic and pelargonic acids.

From Payen and Chevallier's analyses and report the oil was supposed to resemble oils of mustard, asafœtida, &c., and to belong to the ethereal oils containing sulphur; that it dissolved largely in water, and on this account preserved the beer; and that it acted partly as the narcotic in beer and hops.

According to Wagner the oil is isomeric with Borneo camphor, oils of cajeput and bergamot, and with the aldehyde of camphoric acid. This chemist, in conjunction with Dr. Bibra, made experiments upon animals to ascertain whether the oil of hops acted as a narcotic. They found it had no such action.

Lupulin.—This substance is the yellow, granular, aromatic powder which is found at the base of the cones of the hops, and forms from 8 to 18 per cent. of the cones themselves.

Lupulin contains five different substances, viz., a volatile oil, a resin, a nitrogenous substance, a bitter principle, and a gummy substance. The cones contain about 2 per cent. of the volatile oil of hops. The oil and resin combined probably gives to beer its agreeable aromatic odour, whilst the bitter principle (lupulin) tends to preserve it.

The bitter principle of hops, lupulite or true lupulin, may be obtained by treating the aqueous extract of lupulinic grains, combined with a little lime, with alcohol. The solution thus formed is to be evaporated, the mass treated with water, and the solution again boiled to dryness. The residue, on washing with ether, is lupulin. It is uncrystallizable, white, very bitter, soluble in twenty parts of water, very soluble in alcohol, and in ether slightly so. The aqueous solution froths on agitation, and according to Pereira, gives no precipitate with tincture of galls or acetate of lead. Lupulin contains no nitrogen. It is said to have caused loss of appetite and diminished digestive power when administered in small doses.

Dr. Yves first applied the term lupulin to the pollen or, as it is technically denominated, the "condition" of the hop; the name has been applied since, however, to the bitter extract of the scales.

Other Constituents.—The tannin serves, in brewing, to precipitate the nitrogenized or albuminous matter of the barley, and therefore assists clarification.

The resin has a golden-yellow colour, becomes orange-yellow on exposure to the air, dissolves both in alcohol and ether, and is apparently the oil changed by oxidation.

A decoction of hops feebly reddens litmus, owing to free acid being present; sulphuric and tannic acids, and also lime, may be detected in it even by those who have little experience in analysis.

Hops, in their usual marketable state, lose between 11 and 12 per cent. of their weight when dried at 212° Fahr. (100° C.), and leave, on burning, from 5 to 8 per cent of ash.

Holden obtained, on incinerating a good sample of hops, 7·708 per cent. of inorganic residue.

The ash of hops varies very much in its composition, as may be seen from inspection of the analyses given below:—

CONSTITUENTS OF THE ASH OF HOP CONES.

	WAY & OGSTON.			H. WATTS.
	Bentley Variety.	Golding Variety.	Grape Variety.	Grape Variety.
Potash,	11·98	24·88	25·56	19·41
Soda,	—	—	—	0·70
Lime,	17·93	21·59	18·47	14·15
Magnesia,	5·94	4·69	5·27	5·34
Alumina,	—	—	—	1·18
Ferric Oxide,	1·86	1·75	1·41	2·71
Sulphuric Acid,	7·01	7·27	11·68	8·28
Chlorine,	—	—	—	2·26
Silica,	22·97	19·71	9·99	17·88
Carbonic Acid,	5·44	2·17	4·54	11·01
Phosphoric Acid,	21·38	14·47	17·58	14·64
Chloride of Potassium,	5·45	—	4·34	—
Chloride of Sodium,	—	3·42	0·12	—
Charcoal and Loss,	—	—	—	2·44
	99·96	99·95	98·96	100·00
Ash per cent. of dry hops,	8·07	5·95	7·21	—
" " fresh hops,	7·27	5·22	6·52	6·5

Preparation.—The drying of the hop constitutes a very important part of its management; it is performed in kilns, generally of very unscientific construction, and apparently capable of great improvement.

In Sussex these are termed "oast-houses." The heat imparted by the fire in drying is of great importance, and should in no instance exceed 119° or 120° Fahr. (48°·3 to 48°·8 C.).

The farina or pollen which falls through the hair-cloth or wire, in the course of desiccation, is a valuable article, and is denominated "hop-dust." If care is taken that no particles of fire fall into the kiln-pit, and the hop-dust be frequently removed therefrom, so as to insure its freedom from extraneous matter, it is scarcely less useful to the brewer than hops themselves. One pound of the dust is equal to four times the quantity of the strobiles. In dark-coloured or common beer a small amount may always be used without injury.

According to BRANDE, in order to give the hops a good colour, they are subjected to fumigation with sulphurous acid; after this process they are packed into sacks or "pockets," and subjected to great pressure, so as to prevent access of air and their consequent deterioration.

Qualities.—The medicinal properties of hops are numerous. The odorous emanations arising from them possess, according to PEREIRA, marked narcotic properties. Hence a pillow of the cones has often been prescribed to promote sleep, in cases where the administration could not be effected, or would have been objectionable. Probably the imagination has much to do with the effect produced. Both infusion and tincture of hops are mild and agreeable aromatic tonics. They sometimes manifest diuretic, or, when the skin is kept warm, sudorific qualities. Their sedative, soporific, and anodyne properties are very uncertain.

The lupulinic grains are aromatic and tonic, and appear to be soothing, tranquillizing, and slightly sedative and soporific. Hops have been given internally to relieve restlessness consequent upon exhaustion or fatigue, to induce sleep in the wakefulness of mania and other maladies, to calm nervous irritation, and to relieve pain in gout and rheumatism. They have also been applied topically in the form of a fomentation or poultice, as a resolvent or discutient in painful swellings or tumours.

The properties of hops in brewing are important, but may be given in few words.

They render the beer more stimulant and cordial, and the bitter principle overcomes the disagreeable sweetness arising from the malt, and which, if unneutralized, might be offensive, if not injurious, to persons having weak digestive organs.

The stimulating and strengthening qualities found in bitter beer, may be said to be owing almost entirely to the hops.

They are slightly anti-fermentive, and but for the use of them in brewing the ale produced would soon undergo the acetous fermentation, or, in popular language, become sour.

Selection.—The flavour of the Golding or Farnham hops is rich and delicate, but the plant is one of the most tender cultivated, and the crop is uncertain. They are the heaviest, consequently possessing the greatest amount of farina or condition, and the flower is the most diminutive.

The Flemish plant produces a large flower, often 3 inches in length, and is considered as one of the most hardy kinds. It is productive, but of light weight, and is ill-flavoured.

In the districts of Kent and Sussex the Canterbury grape, a very good and useful hop in the trade, is much cultivated.

Other varieties are produced in various parts of the country, especially in a district called North Clay, in Nottinghamshire. These hops are strong, and fit only for porter brewing, even when mellowed by age.

Farnhams are in much repute with brewers, and bring a high price. The North Clays rank next in taste, and fetch a better price with a certain class of buyers than those from Kent, though not generally so high as the Farnham variety. Those grown in the neighbourhood of Canterbury are much prized. The produce of the county of Kent is pre-eminent both for strength and flavour, but varies considerably as the season is more or less propitious. The Wealds are celebrated in some of the southern and midland counties, but in those more north, as in Cheshire and Lancashire, the Worcesters are preferred for their mildness, and for the grateful sensation they yield; some use a few Sussex or Kents with them, but most brewers in the counties just referred to reject the growth of Kent as unpleasing to their customers.

But however good the produce of any district may be in general, it must not be supposed that there are no bad samples of those varieties.

Such lots should be chosen as are heaviest, because it is the farina which gives weight; and hops which lose a part of it from fine weather or over-ripeness, in picking or turning on the "oast," will considerably diminish in gravity.

They should feel clammy when handled, should be uniform in colour, without greenish particles in the flower, and full of hard seeds and farina or "condition." The brighter the colour the greater the estimation in which the sample is held.

Mould may be discovered in the sample by the sprig of the flower being partly bare of leaf. Particular attention must also be paid to crust proceeding from damp or bad keeping, as it injures the quality more than age.

From the uncertainty of the seasons, the hop is an article liable to considerable fluctuations in its commercial value. The duty upon hops was formerly *2d.* per lb., with 5 per cent. added. In 1861 this was reduced to 1½*d.* In 1863 the duty was wholly repealed. Latterly foreign hops have been used to a considerable extent by many brewers, even in the manufacture of the finest ales; they do not, however, possess that richness of flavour so characteristic of the English growth, and hence they are never used alone, but mixed with English hops in different proportions, varying from a third to a sixth of the latter. This mixture is found to answer tolerably well, where considerable bitterness is required and the flavour is thought to be unimportant.

A "pocket" of hops, if they be good in quality, well cured, and tightly pressed, will weigh about 1½ cwt. This is the finest sort for ale-brewing.

The brown varieties used for porter and stout are packed in coarse bags, which should weigh about 2¼ cwts.

If the weight of either sort exceeds or falls much short of this medium there is reason to suspect that the hops are of inferior quality, or have been badly dressed for market.

BREWING.—This operation may be divided into six sections, viz.: 1, Pumping; 2, grinding; 3, mashing; 4, boiling; 5, cooling; 6, fermenting and cleansing.

Pumping.—The water or "liquor" has nearly always to be pumped, and in some cases also the wort or beer. As the pumping of wort or beer will be referred to in other sections, pumping the water, or as it is termed in the brewery "liquor," need only be noted in this.

A good supply of this most important "liquor" is always necessary, and is generally best obtained from a well. A high service of water is in some towns supplied by water works, and occasionally used for brewing. This of course saves pumping, but liquor from a well is generally considered best for brewing purposes. It is also generally colder, and therefore better adapted for refrigerating and attemperating. It is essential that the pumps be large enough to do their work in a short time, so that in breweries of a large size the machinery need not be worked on purpose for pumping only. The liquor is stored in a vessel called a "cold liquor back," and particulars of this vessel will now be described.

Its capacity should be about six barrels per quarter of malt brewed, but the contents may vary considerably. For instance, if there be a regular and good supply of liquor, the back need not be so large as when the supply is uncertain, although it is well to have the back large enough. It should not be unnecessarily large, as it must be borne in mind that fresh liquor is generally the best for brewing. It must be constructed of wood or iron. Generally it is made of wood if indoors, and of cast iron if out of doors. Wrought iron is also occasionally used, but for very small backs only, which are to be placed indoors. Wrought or cast iron may be galvanized, but it is very seldom desired. A few cast-iron backs have been enamelled inside, but since this about doubles the cost, they are not in request.

In position, the water back should be the highest utensil in a brewery, and command every other. It is not uncommon to make it serve as a roof to a part of the building; but some brewers object to the liquor being exposed to the atmosphere, and will have it covered or indoors. When it is outside there must be access to it from the brewery for cleaning, &c. It must on no account be placed over another utensil in such a position that the steam arising from the lower will strike against the bottom of the liquor back. This applies particularly to the iron backs, as the steam would readily condense against the cold iron and become a great nuisance. In proportion the width is frequently about half the length; but length and width are not important. It should not be very deep—say 3 or 4 feet—because, as it is the highest utensil, it requires multitudinous supports, and if shallow, of course the weight is spread over a larger surface.

The liquor back, when full of water, weighs about 4 cwts. per barrel if made of wood or wrought iron, and about 5 cwts. per barrel if in cast iron. When constructed of cast iron it should be made in plates of a convenient size, bolted together with wrought-iron screw bolts. When made of wood the best Dantzic fir should be used.

In places where there is a deficiency in the supply of liquor cold enough for refrigerating and attemperating, machines for the artificial production of cold are now frequently made use of. (See ICE-MAKING MACHINES.) Sometimes these machines are used for making ice, which is put into the liquor to make it colder; but, on account of the large quantity of cold liquor that is required, it is more common to cool the liquor direct, reducing it in temperature about 20° Fahr. (11° C.)—thus largely economizing the quantity of liquor required for refrigerating.

Grinding.—Little need be said on grinding, in addition to what has been already stated under ALCOHOL. It is essential to have the natural cohesiveness of the grain destroyed in such a way that the water may have free access to every particle of it, in order to insure the entire extraction of the valuable constituents. Of the various methods resorted to, whether by reducing the grain between stones in the ordinary way, or by steel mills, wherein it is cut or torn in the same manner as coffee is ground, or by crushing between rollers, that mode is preferable which disintegrates the grain completely, and loosens the husk from the fleshy parts without separating the two.

A moment's consideration will show that these conditions are not fulfilled by either of the first two methods; and it is only by the use of rollers that the malt can be properly prepared. A secondary advantage is gained in the facility with which the mash is racked off, leaving but little of the extract in the grains. When it is ground fine, the malt, besides being apt to "set" and form a mucilaginous magma, retains much of the liquor, which cannot be removed except by long washing, thus rendering the worts dilute, and exposing them to the danger of acetification in the succeeding treatment. When the particles of the grains still adhere, though their natural texture is broken, each shell forms, as it were, a filter, through which the clear liquor percolates readily, leaving any matter which might be taken up mechanically behind. If the grain be torn or sliced, as by the steel cutting mills, in which the contents of the grain remains to some extent adhering to the husk in its natural state, considerable loss will be sustained, for the water will not penetrate these parts during the period usually allowed for mashing. That this is the case is evident from the well-known fact, that dried malt will float on water for a period of twenty-four hours, without absorbing enough of the liquid to increase its gravity sufficiently to cause it to sink.

Fig. 7.

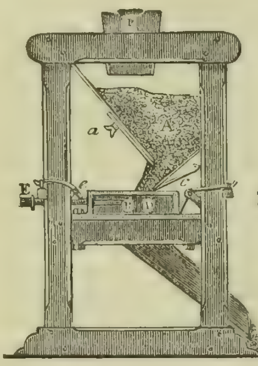
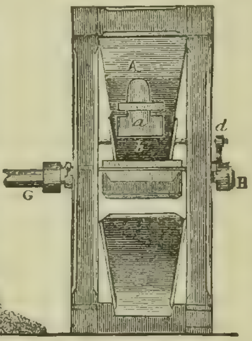


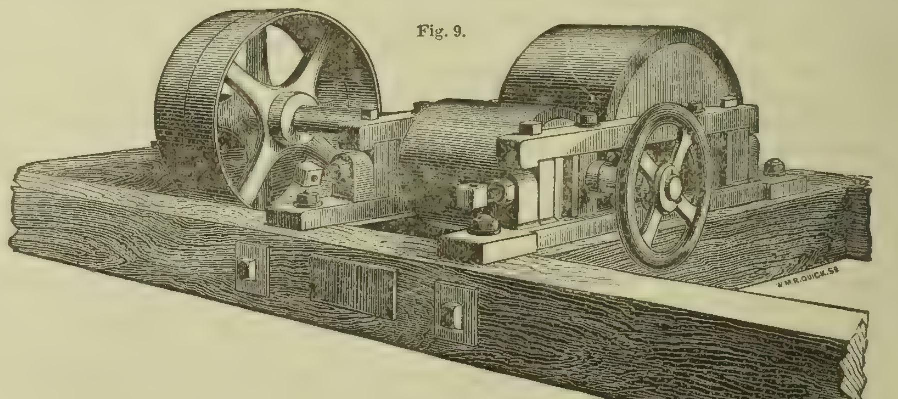
Fig. 8.



The annexed cuts, Figs. 7, 8, represent, in front and lateral section, the cylinder malt mill: I is a sloping trough, through which the malt passes from its bin or floor to its hopper, A, whence it is shaken between the iron rollers, B, D, working at their extremities in bearers or sockets of hard brass, fitted securely into the side frames, which are also of iron: E is a screw passing through the upright, and serving to force the bearer of one roller towards that of the other, so as to bring them nearer together when the malt is wanted in a finer state of division: G is the square end of the axis, by which one of the rollers is turned. The other rotates by means of a pair of equal-toothed wheels, H, fitted to the opposite extremities of the axes of the cylinders: *d* is a catch working into the teeth of a ratchet wheel, not shown in the engraving, on the end of the rollers. The lever, *c*, comes in contact with the trough, *b*, at the bottom of the hopper, giving it a shaking motion, which discharges the malt upon the rollers from the side sluice, *a*. *e e* are scraper-plates, the edges of which, pressing on the rollers, remove adhering matter, and thus keep them clean.

The malt is in the best breweries now ground, or more properly speaking crushed, in the mill sketched at Fig. 9. It is made to pass between cast-iron rollers with smooth surfaces, the rollers varying in size and proportion according to the quantity to be crushed; but it may be taken that the malt crushing rolls should be capable of crushing as many quarters per hour as are mashed in one operation. Their dimensions therefore vary from 8 inches wide and 8 inches diameter to any required size.

Fig. 9.



It is now generally preferred to make one roll about twice the diameter of the other, and to drive only the larger roll, the smaller roll revolving by the friction of the malt passing between the two. These rollers are furnished with set screws so as to regulate the space between them for the passage of the malt (Fig. 9). It is most essential that good smooth surfaces be maintained on the rolls, or otherwise the crushing will be imperfect, and the uncrushed malt unproductive.

The rolls should be furnished with a wire screen to take out the dust, stones, &c., that may be in the malt. They should not be driven too fast, or the grist will become heated. In some breweries the malt is screened into different sizes, and each size is crushed by a separate pair of rolls differently set, so as to insure every grain being crushed to the same extent.

In large breweries, where the malt is frequently stored in bins, a good adjunct is KING's patent grain measurer, which registers the quantity of malt passed through it. It consists of a revolving wheel or drum with compartments.

The position in the brewery of the malt rolls is important, as the malt hopper (generally made of wood) should be commanded by the malt store, so that the malt can be shot directly into the hopper, and run into the rolls. Where the malt rolls are obliged to be above the store, it is necessary to have an elevator, or Jacob's ladder, to carry up the malt. The elevator consists of an endless band of leather, upon which are fastened metal buckets, running on pulleys driven by steam power, the band being inclosed by wood or iron casing. When the malt has to be conveyed some distance horizontally to the malt rolls, it is generally done by means of an iron screw revolving in a tube, the screw being formed by an iron shaft having a blade of sheet iron running the whole length; such an one may be seen in ALCOHOL, Plate 1.

When the malt has passed through the rolls it is called grist, and usually runs into a wooden hopper called the "grist case," erected over the "mash tun." The grist case, like the malt hopper, is generally made of wood, the large ones sometimes of iron; it should contain sufficient material for one brewing. Where the malt rolls have been placed too low to command the grist case there must be an elevator, as above described, to raise the grist to the required height.

It may be mentioned that where the malt store is in the upper part of the building, it should be furnished with a sack tackle for raising the sacks of malt. In large breweries several pairs of rolls are used, as it is not found advisable to make rolls to crush more than 30 quarters per hour; and in such cases it is usual to keep one or more pairs of rolls especially for crushing the black malt used for porter and stout.

Mashing.—Mashing is the most important part of brewing, as by it the brewer extracts the saccharine principle from the malt; and hence his profit entirely depends upon the success of this operation.

The process of mashing depends on the action of diastase upon starch, under the influence of heat and moisture. (See ALCOHOL.) Roughly speaking, diastase has the power of converting about 2000 times its own weight of starch into grape sugar.

The theories which have been broached from time to time as to the action of diastase upon starch have been very various. MÜLDER, whose researches on the chemistry of brewing were made some years ago, supposed that the action of this soluble albuminous matter was to convert the starch into dextrine in the first place, and then afterwards to convert some of that dextrine already formed into sugar. SCHWARZER more recently took the same view—viz., that dextrine is first of all formed, and then afterwards converted into sugar. He states that at temperatures above 65° to 70° C. the ratio of glucose to dextrine is as 1 to 3; whereas below 60° C., that is below 140° Fahr., the ratio is about equal — viz., 1 glucose to 1 dextrine. MUSCULUS, on the other hand, has concluded from his researches that 3 parts of starch, when thoroughly acted upon by diastase, produced 2 of dextrine and 1 of sugar. C. O'SULLIVAN, the scientific adviser of Messrs. BASS & Co., asserts that neither dextrine or glucose are formed at all, but a species of sugar (maltase) having a structure intermediate between that of grape sugar and starch.

Diastase is by long digestion dissolved out in greater quantity from the malt at low temperatures than at high, and it has been observed that the temperatures at which its solution is most complete is between 100° to 140° Fahr. (37°·7 to 60° C.), whereas the temperature at which it is most active in converting the soluble matters of the mash into a more sugary or saccharine form is much higher.

At low temperatures dextrine is uniformly produced along with the sugar, and then as the temperature gradually rises, more and more of the sugar is obtained, until a point is arrived at, at which this action upon dextrine can go no further.

Before stating the particular operations of mashing, it may be well to make a few allusions to the quantity of extractive matter usually obtained from malt, and the problem of its thorough exhaustion, a point which is the grand aim of mashing. From the analyses given of malt, as well as those of barley, it will be seen that the available constituents of the former amount to 78·3 per cent. when dried by the ordinary means; and as a quarter of good malt generally weighs 352 lbs., it follows that 275·5 lbs. of these are available valuable matters, the remainder being water and husk. It is to be borne in mind that all this quantity is not saccharine matter, but that there exists in it a variable proportion of albumen and gluten; these, however, are abstracted to a great extent in the mashing, and are afterwards removed, as will be seen further on. Now, the best practical results average about 90 to 95 lbs. per qr., as shown by the specific gravity saccharimeters; but as every unit of this number equals 2·6, or, according to DRING and FAGE, and CASARTELLI, 2·7 lbs. of real extract, it is evident that the total of the valuable ingredients is 234 to 249 lbs.; for 90 × 2·6 = 234; and 95 × 2·6 = 249; but if the calculation be made according to the latter authorities, the produce will be 243 and 256·5 lbs.

It is, however, easy for the brewer to ascertain when he is successful in his exhaustions, and also what ought to remain after fermentation to give body to his product. He should also be able to find the amount of extract in a wort from the gravity of the liquor, as indicated by the saccharimeter, without the necessity of recurring to the tables, or sliding rules accompanying them; for it frequently happens that errors creep into such calculations, and the results they point to are sometimes greater, sometimes less, than the real amount contained in the worts. To do this, all that is required is to multiply the indication by 2·6, or 2·618—2·7 according to CASARTELLI—and the product will be the real weight of extract in each barrel of the wort.

By this means the total extract per quarter in the first mash may be found, and by deducting it from 275·5 the remainder is what is left in the grains to be extracted in the next mash; knowing this, the amount of liquor employed may be regulated accordingly, so as to obtain a dense wort, and thereby avoid the danger of acetification, to which dilute worts expose the products.

The process of mashing differs somewhat according to the use to which the worts are to be put. It is the object of the vinegar maker to obtain a wort of such strength, or containing so much saccharine matter, as will give a product affording, after the fermentation and oxidation of the alcohol, about 5 per cent. of acetic acid. The distiller desires to extract the valuable principles entirely, and produce a wort which will completely ferment, leaving as little saccharine matter as possible in the liquor. The brewer wishes to have a dense extract (which shall neither acetify nor, at the same time, be wholly converted into alcohol); and so to restrict the amount of alcohol that the liquor will merely communicate a pleasant hilarity to those partaking of it, reserving the greater portion of the malt extract for communicating to his beer richness, unctuousness, and flavour. If he leaves these particulars, or any one of them, unattended to, his beverage will become very quickly distasteful to his customers.

The first important point with the brewer is the complete abstraction of the soluble substances in his malt; the next, and not less important point, is that he is to effect it with the smallest possible quantity of liquor, it being understood that he must be rigorously careful to prevent any acidification. Six or seven barrels of water per quarter of malt are generally sufficient for the exhaustion, of which 2¼ to 3¼ barrels are lost in the after operations of boiling and fermenting.

MUSPRATT thinks that too much water is used. He says that it is plain that the diastase and gluten of the malt are capable of transforming a much larger quantity of starch into sugar than what is present, and it is no less obvious that the water employed is sufficient to hold in solution a far greater proportion of the saccharine substance than it can possibly meet with in any brewing operation; it therefore follows that the methods adopted are defective, inasmuch as an unnecessarily large quantity of fluid is used to attain the results which, according to the known properties of the constituents, might be accomplished with less.

It is well known that the diastase of the malt is most active when the liquid is rather dilute, and the temperature is between 160° and 170° Fahr. (71°·1 to 76°·6 C.); the latter might be injurious at the outset in a brewing operation, but the former, or even 165° Fahr. (73°·8 C.), can be applied with safety. Hence it is apparent, that by sustaining an equalized temperature, and with the use of a moderately large quantity of water, the conversion of the starch into glucose will be complete, and that it can be almost entirely extracted in the first solution, leaving nothing in the first mash for the subsequent sparging, but to wash out that portion imbibed by the grains. By accomplishing this with 4 to 5 barrels, instead of 6 to 7, the brewer would derive material advantage, as the "lengths" which are at present employed, and subsequently expelled by evaporation, &c., would to a great extent be unnecessary. Another inducement to the adoption of means for obtaining dense worts is one which brewers must necessarily value, namely, the production of sound beer; for it is impossible to brew a good beverage from an inferior wort; and when the latter is weak, the tendency to acetification is far greater than when a heavy extract is used.

Considerations like these ought to be sufficient to check the practice of varying, in almost every brewing, the manner of mashing; now applying a low temperature, then a high one, but always using repeated mashings, which entail the trouble of continued boiling afterwards, and ultimately impair the quality of the beer.

The chief point is to apply so much water, and maintain such an initial temperature, as will, on sufficient time being allowed, completely disintegrate the grains at one mashing, and leave nothing for the subsequent abstractions but what remains of the first in their pores. This is the highest perfection in mashing.

The temperature of the liquor which is mixed with the malt varies between 160° and 170° Fahr. (71°·1 to 76°·6 C.); in some cases even more. This variation of temperature, however, depends upon several conditions. First, on the amount of radiation that may take place from the mash tun itself; secondly, on the specific heat of the malt used, because this varies in different malts; and, thirdly, on the particular class of ale which is to be brewed. If it be a strong ale less hot water will be used than if it be a weak one.

The English method of infusion depends upon using a high initial temperature. The following table by Dr. GRAHAM shows the amount of the several constituents named after three hours' mashing:—

ENGLISH MASHING PROCESS AT A HIGH INITIAL TEMPERATURE.

	140° Fahr.	150° Fahr.	160° Fahr.	170° Fahr.	175° Fahr.
Wt. of Extract per c.	70·00	69·75	69·00	67·25	—
Draff, ... "	22·28	23·65	23·96	24·39	—
Glucose, ... "	33·35	30·50	29·41	20·79	15·62
Dextrine, ... "	32 50	34·11	34·33	—	—
Soluble starch, "	none.	traces.	small quantity.	41·13	—

From the above it may be seen that the higher the temperature the less sugar is there in the extract, and there is still more unconverted starch.

The usual routine of mashing will now be described.

The first point to be attended to in a brewery is scrupulous cleanliness, particularly in the various vessels, lest any albuminous substances should be left adhering to them, which, by entering into a putrescent fermentation, might thus communicate the same to the worts, and prove highly detrimental. It is hoped that the importance of this requirement is well understood, since its being overlooked would ruin a brewery, however much skill might be displayed in other ways. The only means of securing this point are to wash the various backs, boilers, coolers, and other utensils, occasionally with lime-water, made by macerating a bushel of quicklime in about twenty barrels of water, or to have all the vessels made of metal; it would be desirable, also, to keep any backs, or other vessels which may not be constantly in use, full of water till such time as they are needed. The manager should be likewise careful to keep the mash-tun perfectly clean; for if any grains should remain in it after a previous brewing, their albuminous contents might suffer decomposition, and give rise to or induce an acid fermentation, which, if absorbed, would prove destructive in the succeeding brewing. Too much precaution cannot be used in guarding against these causes of mischief, which, though apparently trifling in themselves, so operate as to cause the brewer heavy losses.

Unless the brewer mashes every day, it would be well that he should attend to all the preliminaries required for the proper execution of his task previously to the day of brewing; the coppers should be charged with liquor, and sufficient fuel to sustain the fire for heating the materials should be provided. Where the mashing is performed daily, these requirements are secured as a matter of course.

The work, on the day of brewing, should be vigorously proceeded with as early as possible, and especially in hot weather, which demands on the part of the operator greater vigilance and care to secure success.

It is customary to have a journal, wherein the temperature of the atmosphere, the quantity of malt, the heats of the different mashings, as well as of the tap, and other particulars, are recorded.

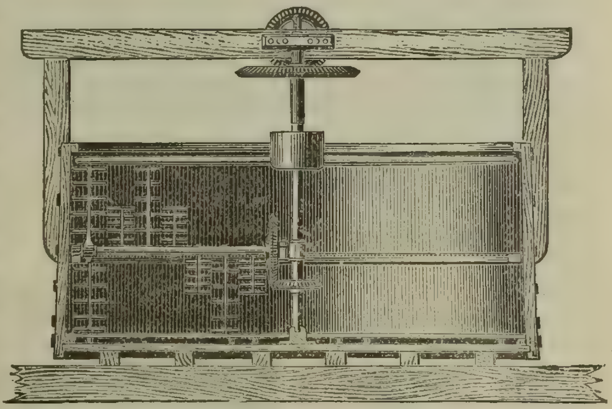
The malt, of whatever description it may be, should be ground if possible the day previous to mashing, but at most it should not be retained longer than three or four days crushed before it is submitted to the mash-tun; for if long kept it will attract moisture from the atmosphere, become heated through the effects of an internal decomposition of the saccharine substance, and render the beer bad in quality.

As previously noticed, the ground malt is usually conducted, in well-regulated breweries, by an Archimedean screw to the hoppers over the tun in the mashing-room, which serve as magazines for it, and whence it is let into the latter when fit, and macerated with water. There are two modes of accomplishing this mixture—one by manual labour and the other by machinery; but the latter is preferable on all occasions, as it is much more effectual in breaking up the masses of malt which are apt to form in the water. Indeed, very often serious injuries arise from the "balling" of the malt, when the mashing has been carelessly performed with oars, or too large a quantity of water has been run upon it at first; for besides being wasted by enveloping a certain volume of air, and being but partially wetted and surrounded by an elevated temperature, the agglomerated portions very quickly generate acetic acid, unless they are rapidly broken up.

Although it has been generally supposed that to get a good extract it was necessary to well mash or beat the liquor and malt together; nevertheless, within the last few years, many brewers have been of opinion that a perfect saturation of the malt is sufficient, although there are some who do not agree with this latter view.

The mashing is performed in a vessel called a mash-tun by means of machinery, the various forms of which will be presently described. The mash-tun itself should contain from 3 to 3½ barrels per quarter of malt to be mashed. It must be of a cylindrical form, and from 3 to 6 feet deep, according to the capacity required. It is constructed of English oak staves with Dantzic fir bottom, or of cast iron put together in the same manner as described for the cold-liquor back. In position the mash-tun must be commanded by the hot-liquor copper, or other utensil in which the liquor is heated; and in its turn must command the vessel in which the wort is boiled, unless the wort be, as is sometimes the case, pumped up into the wort-boiling vessel.

Fig. 10.



Many years ago mashing was done by simply stirring by hand with wooden oars, which was a very imperfect method; much of the "goods," as the wetted grist is termed, was frequently left untouched, and consequently was imperfectly productive. The form of the mashing machine then introduced (patented by Matterface in 1807) has been used with very few alterations down to the present time (Fig. 10). It consists of a vertical shaft driven by steam power from above, and working in a footstep with gun-metal bearing bolted to the centre of the bottom of the mash-tun inside; half way down the mash-tun, inside, is bolted a toothed rack, in which works a toothed pinion on end of an iron shaft, and the other end of the shaft works in a gun-metal bearing attached at its proper height to the vertical shaft. This horizontal shaft, or "rake shaft," as it is commonly termed, works round the mash-tun by the vertical shaft revolving, and in its turn is made to revolve by a pair of bevel toothed wheels, one on the vertical shaft and one on the rake shaft. The rake shaft is provided with a number of wrought-iron oars, or rakes, generally about 8 inches wide, and by these means the mashing is effectually accomplished. Although some other forms of internal mashing machines have been used, they have not been generally adopted.

In a few instances brewers objecting to iron have gone to the great expense of having the mashing machine made entirely of gun metal.

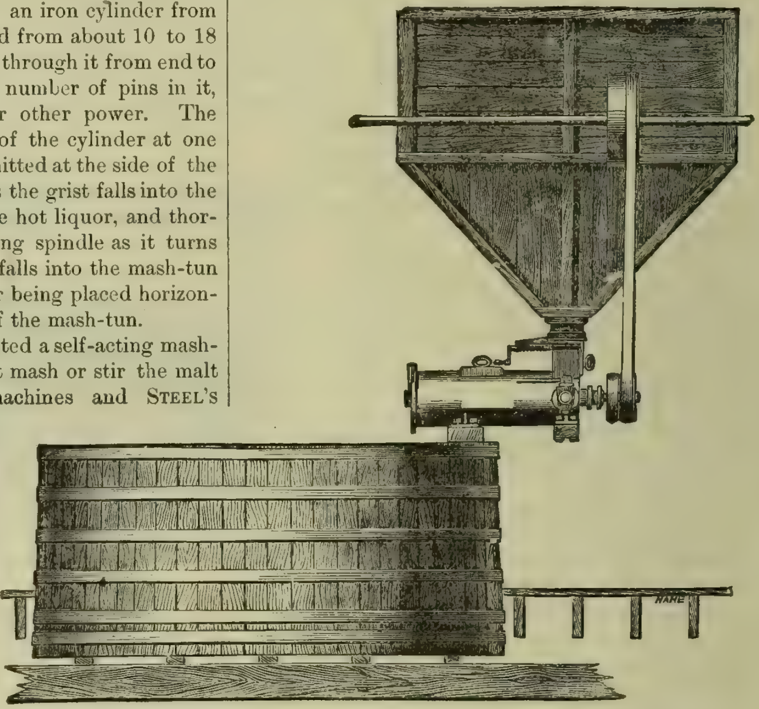
In 1853 W. Steel patented an external mashing machine which has been, and is, very extensively used (Fig. 11). It consists of an iron cylinder from about 3 feet to 6 feet long, and from about 10 to 18 inches in diameter. Running through it from end to end is a spindle with a large number of pins in it, which is driven by steam or other power. The grist is admitted into the top of the cylinder at one end, and the hot liquor is admitted at the side of the cylinder at the same end. As the grist falls into the cylinder, it is there met by the hot liquor, and thoroughly mashed by the revolving spindle as it turns in the cylinder, after which it falls into the mash-tun at the other end—the cylinder being placed horizontally on the top of the edge of the mash-tun.

In 1863 C. Maitland patented a self-acting mashing apparatus, which does not mash or stir the malt as the internal mashing machines and Steel's machines do, but simply thoroughly saturates the malt on its way to the mash-tun; many brewers believing this to be all that is necessary for obtaining a good extract. This very simple apparatus has ever since its introduction been extensively used (Fig. 12). It consists of a copper double cylinder from 16 to 36 inches high, and from 6 to 12 inches in diameter. This cylinder is fixed vertically to the bottom of the grist case. The hot liquor is admitted through the outer cylinder, and the inner cylinder being furnished with a number of perforations, and a jet throwing upwards from the bottom, the grist, as it falls through, comes in contact with numerous streams of hot liquor, thus insuring that every grain is thoroughly saturated with liquor at the same temperature.

With the internal mashing machines the whole of the grist is turned into the mash tun before the mashing commences. The hot liquor is then admitted at the bottom of the mash-tun, and when a sufficient quantity has been allowed to pass in, the machine is put into motion. It follows that in using the internal mashing machine every grain does not come in contact with liquor of the same temperature, as the latter is considerably cooled by coming in contact with the cold grist at the bottom of the mash-tun before it wets the upper portion of the grist. This, of course, is obviated by using an external mashing machine like Steel's or Maitland's, either of which is very frequently used in addition to the internal mashing machine. The great advantage of Maitland's mashing machine is its simplicity and lowness of cost; having no moving parts there is nothing to get out of order, and not requiring any motive power, the cost of the driving gear required for other machines is saved.

Other external mashing machines have been introduced during the past few years; but not having met with the success of Steel's or Maitland's, need not be described here.

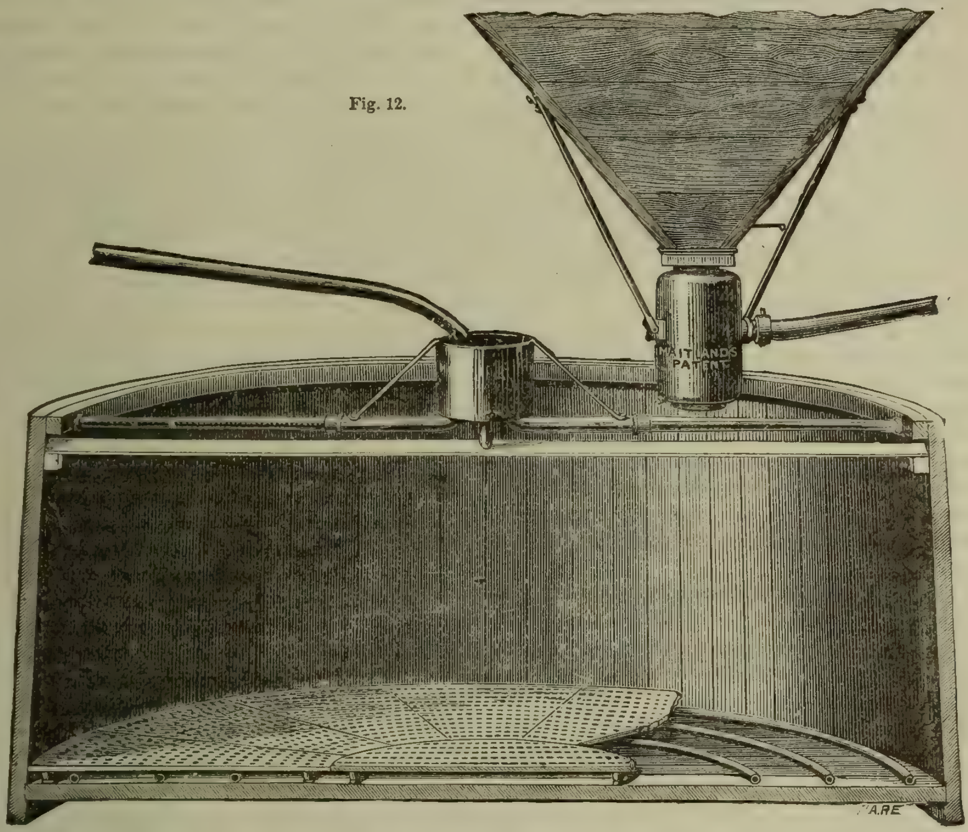
Fig. 11.



The mash-tun is provided with a false bottom to strain the wort from the grains. The extract is called wort when it is drawn from the mash-tun, and the malt then left behind is called grains. The false bottom is usually made of cast iron in plates of a convenient size, and about ⅜ths of an inch thick, having perforations about ⅛th of an inch in diameter, and about 1 inch apart all over, and countersunk on the under-side. The false bottom is usually placed about 2 inches above the bottom of the mash-tun. Originally the perforations used to be cast, but they were then so irregular in size that it has been found much better to drill them, which is now invariably done. False bottoms are sometimes made of cast gun metal or wrought copper, and these are now in much greater request than they used to be.

The bottom of the mash-tun is frequently fitted with a grain door, through which the grains are thrown out when done with.

Fig. 12.



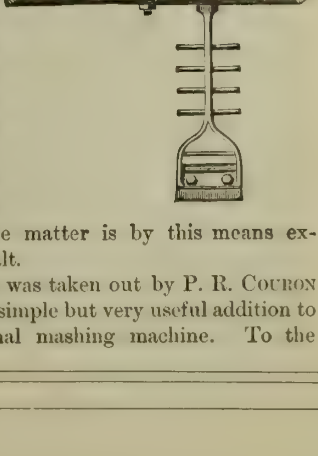
The wort is drawn off from the mash-tun by means of several cocks or taps, called "spend taps." About four to six are usual, so as to draw from all parts of the tun. As it is important to the brewer to get the wort off bright, having several "spend taps" enables him to close one or more from which the wort may not be running bright.

After the first mash is completed a further quantity of hot liquor is put over the top of the "goods" by means of a "sparger." This sparger revolves on the well-known principle of Barker's mill. It has a copper basin in the centre, into which the hot liquor is admitted, thence passing through two or more perforated arms extending to the sides of the mash-tun. Where there is an internal mashing machine the basin is made so that the upright shaft of the mashing machine passes through it, and the basin runs on wheels fixed to a carriage on the upright shaft. Where there is no internal mashing machine the basin turns on a pivot (Figs. 10 and 12), or sometimes on a joint somewhat like a ball and socket joint.

When the wort is drawn from the mash-tun it runs into a vessel called the "underback," which need not be of sufficient capacity to hold anything like the whole quantity of wort, as it is from the "underback" at once run or pumped up into the wort copper for boiling. As it is always desirable to maintain the temperature of the mash and the wort uniform, a mashing attemperator is frequently applied to the mash-tun. A very effective form of mashing attemperator, and the simplest, is a coil of copper pipe placed underneath the false bottom (Fig. 12), the steam being passed through it as required. The same thing is often applied to the underback, so that the temperature of the wort may be maintained on its way to the copper. The mashing machine is sometimes driven from below with a stuffing box through the bottom of the mash-tun; but this method should not be adopted unless unavoidable. Small sizes may be worked by hand. Large size machines have two or more rake shafts.

After the first mash a second is made in a similar manner. All the remaining saccharine matter is by this means extracted from the malt.

Fig. 13.



Recently a patent was taken out by P. R. Couron (Fig. 13) for a very simple but very useful addition to the ordinary internal mashing machine. To the ends of the ordinary rakes are fixed flexible strips or brushes of pliable material, vulcanized india-rubber being found the most suitable, which in their revolution sweep aside and effectually stir up the grain in the mash-tun.

It is well known that, unless the malt is coarsely ground, the goods are liable to settle on and clog the holes of the false bottom, thereby preventing the even flow of the taps, and proper percolation of the sparged liquor through the goods, thus causing delay, and in the summer time endangering the soundness of the wort. On the other hand, the malt coarsely ground will never yield its full extract. Couron's patent enables the rakes to act really upon the false bottom of the mash-tun and sweep aside the grain, thus clearing the holes and insuring a more thorough mixing of the contents of the mash-tun.

After mashing the tub is carefully covered down, to preserve the heat of the mash and exclude the air from the wort as much as possible; and having been allowed to rest for about two hours, it is then drawn off to the copper; an operation which must be performed with great care, to insure the liquor being perfectly bright, and free from any solid particles of malt.

At this stage the sweet liquor is apt to enter upon the vinous fermentation, and thence to pass to the acetic, to prevent which the temperature is raised to ebullition, and the hops added; meantime the partly exhausted malt, after the whole of the liquor has been drawn, is to be subjected to a second operation. For this purpose the tub is uncovered, and a fresh quantity of water, the amount of which is regulated according to the density of the first worts, or the quantity of the matter yet unextracted, is turned on at the proper heat, and mashed by one of the foregoing machines; the tub is then covered, and the whole allowed to digest for one hour, or less, according to circumstances, and then drawn off as before. By proper attention the whole of the requisite constituents of the malt should be taken up by these two mashings; sometimes, when the mash is very stiff, a third sparge is let in upon the grist to exhaust it, but the product is used only for *table beer*.

Having, in the above short sketch, given an outline of the whole course of mashing, a few remarks in explanation of the process will now be added. It is the custom with a great many brewers to let the water into the tun at a higher degree of heat than is required by the mash, and allow it to cool down to the proper temperature before the malt is introduced. Others, again, admit the malt and heated water simultaneously, while the machine, being put in motion, mixes them thoroughly. In the latter instance, it is plain that the heat of the liquor must be much higher than the initial heat at which the constituents of the malt should be extracted (namely, 160° Fahr. (71°·1 C., or thereabouts), for the water communicates part of its heat to the mash-tun, as likewise to the goods, and thus causes a decrease of 20° or 30° Fahr. (11° to 16°·5 C.) or more, according to the state of the weather. It is equally obvious that the mixing of the malt and a liquor of 180° or 190° Fahr. (82°·2 to 87°·7 C.) is unadvisable; for although, in the event of mixing them, a mean temperature of 158° or 160° Fahr. (70° to 71°·1 C.) may result, yet the starch, albuminous, and glutinous part, cannot but be rendered insoluble in those portions with which the solution comes in contact at the commencement.

On the contrary, if the water be poured in at 170° Fahr. (76°·6 C.), or under the mean, after fifteen or twenty minutes it will be far below that at which the diastase and gluten are most active in converting the starch into glucose. The conclusions from these observations evidently favour the heating of the mash-tun with the water, and when it has been reduced to 165° (73°·8 C.), or between this and 170° Fahr. (76°·6 C.), to admit the malt from the hopper, and mash rapidly. In this case the malt is the only body which can abstract the heat, and the slight elevation of the temperature supplied for meeting this decrease does not react so injuriously upon the goods as in the first case.

Others, again, turn on as much water at a low degree of heat as will moisten the malt completely, and cause it to swell, after which the remaining quantity of water required to make up the wort is let on at 190° to 194° Fahr. (87°·7 to 90° C.), and mashed in the usual way. This method is said to be advantageous. First, by lessening the tendency to set. Second, by giving the diastase greater scope for acting upon the starch, since the greater part of the sugar is dissolved out in the first wetting, and the residual portion is more permeable to the solution, which, having a temperature of about 165° Fahr. (73°·8 C.) as its mean, is very effective in exhausting the goods.

It should be remembered, however, that diastase is very soluble, and that it is wholly, or to a great extent, removed with the sugar, leaving only the gluten in proximity with the starch to effect its solution. During the subsequent part of the operation, when the water of a higher temperature is poured on, many authorities of long experience affirm that the particles of this active principle are placed at such a distance from the starch that the diastase cannot exert the same influence as if it and the starch were exhausted at the same time.

The quantity of water which is usually taken varies from 1½ to 2½ barrels per quarter of grist for the first mash, according to the system of working followed by different persons; but if the mean temperature could be sustained throughout the mashing, it is quite evident that 1 barrel, 6 firkins, which weighs about 630 lbs., would be even more than sufficient to exhaust the quarter of malt of its soluble ingredients, consisting, as they do, principally of glucose or saccharine matter, which requires only 1·33 parts of cold water for its solution, and much less when the temperature is raised as in mashing.

From all these peculiarities, it seems that the general defects of mashing are:—1. Inefficient extraction in consequence of the gluten and portions of the starch of the grain forming a gelatinous mass which envelopes the starch and sugar, and does not allow the water to flow off, in consequence of too elevated a temperature. 2. Non-conversion of the starch into glucose in consequence of too low a temperature. In the subsequent operations this kind of wort is prone to acidify and spoil, particularly if the time of mashing and tapping be long.

It is evident that the maintenance of a due degree of heat, and the employment of the proper amount of liquid so as to have a dense wort, are the two chief points which should attract the brewer's attention; and if he could surmount all the difficulties arising from long custom, based upon imperfectly understood principles, and make the attempt to add science to his working practice, it is evident that a considerable part, if not all the loss which is at present so generally sustained by brewers, might be converted into profit.

The following table relating to the temperature and time of the standing of the mash, &c., is by LEVESQUE, and throws considerable light on this point. It should be remarked, however, that the heat of the mash water varies according to the malt employed, that for pale malt being the lowest, whilst for high-coloured it may be poured on at a much more elevated temperature. The degrees marked are Fahrenheit:—

Temperature of the air at mashing.	CLASS I. Heat of the mash 14[illegible]° to [illegible]°.	Time of standing of the mash.	Temperature of the air at mashing.	CLASS II. Heat of the mash 145° to 147°.		Time of standing of the mash.	Temperature of the air at mashing.	CLASS III. Heat of the mash 144° to 146°.		Time of standing of the mash.	Temperature of the air at mashing.	CLASS IV. Heat of the mash 143° to 145°.		Time of standing of the mash.
	Firkins per quarter 6.	h. m.		Firkins per quarter 7.	Firkins per quarter 8.	h. m.		Firkins per quarter 9.	Firkins per quarter 10.	h. m.		Firkins per quarter 11.	Firkins per quarter 12.	h. m.
10°	197·00	4·00	10°	189·00	184·00	3·00	10°	178·00	175·00	2·00	10°	172·00	170·00	1·00
15	195·17	4·00	15	187·42	182·59	3·00	15	176·84	173·92	2·00	15	171·00	169·19	1·00
20	193·34	4·00	20	185·84	181·18	3·00	20	175·68	172·84	2·00	20	170·00	168·28	1·00
25	191·51	4·00	25	184·26	179·77	3·00	25	174·52	171·76	2·00	25	169·00	167·37	1·00
30	189·68	4·00	30	182·68	178·36	3·00	30	173·36	170·68	2·00	30	168·00	166·46	1·00
35	187·85	4·00	35	180·10	176·95	3·00	35	172·20	169·60	2·00	35	167·00	165·55	1·00
40	186·02	4·00	40	179·52	175·54	3·00	40	171·04	168·52	2·00	40	166·00	164·61	1·00
45	184·19	4·00	45	177·94	174·13	3·00	45	169·88	167·44	2·00	45	165·00	163·73	1·00
50	182·36	4·00	50	176·36	172·72	3·00	50	168·72	166·36	2·00	50	164·00	162·82	1·00
55	180·53	4·00	55	174·78	171·31	3·00	55	167·56	165·28	2·00	55	163·00	161·91	1·00
60	178·70	3·40	60	173·20	169·90	2·45	60	166·40	164·20	1·50	60	162·00	161·10	0·55
65	176·87	3·20	65	171·62	168·49	2·30	65	165·24	163·12	1·40	65	161·00	160·19	0·50
70	175·04	3·00	70	170·04	167·07	2·15	70	164·08	162·04	1·30	70	160·00	159·28	0·45
Heat of the tap from 141° to [illegible]°			Heat of the tap from 145° to 14[illegible]°				Heat of the tap from 14[illegible]° to 144°.				Heat of the tap from 141° to 145°.			

In the first column under each class of this table, the temperature of the atmosphere at the time of mashing is noted; the next columns are the degrees at which the water should stand to bring the mash to the points at the head of the columns, and the figures at the foot specify the temperature at which the tap stands.

Mashing in this way often causes much variation in the results, owing to the dryness or particular quality of the malt, and the state of the atmosphere. When very dry malt is used, on mixing it with water of a certain heat the resulting temperature is not an arithmetical mean of the two, but is somewhat higher, owing to an elevation of a few degrees, caused by the conversion of starch into sugar, and its solution in water. This fact should be kept in mind when adding the water for the mash, and its temperature regulated accordingly.

When barley is mixed with twice its volume of water, the heat arising from this mixture will be about the mean temperature; but if pale malt be similarly treated the result will exceed the mean; and if highly dried brown malt be taken, the thermometer will indicate a rise of 40° Fahr. (22° C.) over the mean: this elevation always takes place in the first mash, during which the conversion of the starch proceeds with the greatest activity. Such results do not, however, always attend the mixing of the water and malt, as when the latter has stood some time after grinding, it absorbs water from the atmosphere and becomes "mellowed," in which case the development of the heat is not so great as when the goods are perfectly dry; hence, when mashing such mellowed malt, the liquor ought to be somewhat hotter than that which is used with the fresh.

Another circumstance which influences the heat of the mash is the bulk of materials taken; thus the temperature, when only 2 barrels of water per quarter are employed, needs to be higher than if 3 are taken, notwithstanding that the rise by mixing is greater in the first instance.

DONOVAN, speaking of the temperature to be employed in mashing, lays down the following as a general rule:—For well-dried pale malt, provided the atmosphere does not exceed 50° Fahr. (10° C.), the heat of the first mash water may be, but should never exceed, 170° Fahr. (76°·6 C.); that of the second, 180° Fahr. (82°·2 C.); and for the third, 185° Fahr. (85° C.), but never beyond.

It may be observed that the danger of acetification of dense worts at a temperature of 160° Fahr. (71°·1 C.), is not incurred by a slight prolongation of the time of mashing and setting, as might be at first apprehended, for both are unfavourable to the change. (See ACETIC ACID and VINEGAR).

Now, if the agitation of the goods by the machine be continued only for a short time, say from half an hour to an hour, the question might be asked:—Will the conversion of the starch be completed during that time? Again, during the subsidence of the grains and other matters distributed through the liquor by the mashing, will the whole of the starch become saccharified? The answer to each of these questions being in the negative, it must be concluded that the shortness of the time of mashing, and the ineffectual methods adopted for maintaining a suitable temperature, are the chief causes which operate against the obtaining of dense worts, and in favour of acetification. Allowing that the mashing is successful in discharging the whole of the starch and other valuable matters from the grain, and that nothing is left in the shell (which, however, is not so); on the suspension of the motion in the mash-tun the chief part of the starch remains unacted upon, and as the grains fall to the bottom they carry considerable portions of the goods with them out of the reach of the solution. The increased gravity of the liquors, in consequence of the portion of glucose that is formed, also precipitates and hastens the descent of the yet unconverted starch, leaving in a short time the upper part of the liquid clear, and of a very low density. Certainly, the quantity of wort imbibed by the grains assists in the change into sugar, but the transformation is not nearly so effectual as if the contents were disseminated through the bulk of liquid taken for the mash. Another consideration which tends to show that the prolonging of the mash, provided the due degree of heat is kept up (as by a suitable attemperator), would not cause the time of "setting the tap" to extend beyond the usual period allowed in the generality of breweries is, that the chief part of the starch being saccharified whilst the liquid is in agitation, the time afterwards necessary for the clearing of the wort would not be so long as in ordinary cases; for the grains, the sinking of which is to be effected, being dense and in large masses, would readily subside, and the delay caused by the very slow descent of the minute particles of starch still floating in the liquor to the bottom of the tun would be avoided.

Dr. CHARLES GRAHAM recently made a series of experiments to see the amount of action that took place at different temperatures in a given time. He says:—Firstly, I took cold water at 60° to 70° Fahr. (15°·5 to 21°·1 C.), and raised it up to the temperatures indicated in the table below, and kept them at those respective temperatures for two hours. At the end of that time I digested the first at 100° Fahr. (37°·7 C.), and found 24 per cent. converted into sugar; when it was raised to 110° Fahr. (43°·3 C.), 30 per cent.; at 120° Fahr. (48°·8 C.), 32 per cent.; at 130° Fahr. (54°·4 C.), 35 per cent.; at 140° Fahr. (60° C.), 37½ per cent.; and the dextrine also increased.

	100° F.	110° F.	120° F.	130° F.	140° F.
Glucose, per cent.,...	24·19	30·00	32·17	35·71	37·50
Dextrine and starch,..	34·00	29·25	27 33	24·11	26·70

Showing a gradual increase in the amount of sugar formed. The total amount of extract gradually increased, but at 140° Fahr. (60° C.), instead of being a gradual process, there is a sudden leap, and at that temperature there is a much greater amount of extract.

The next point that occurred to me was to test the truth of the German brewers' theory about the range of temperature of 165° to 167° Fahr. (73°·8 to 75° C.), being the most favourable for the conversion of starch and dextrine into sugar. The mashing heat was started on the principle of a low initial temperature raised up in the first hour to 100° Fahr. (37°·7 C.). It was then kept for two hours at a temperature of 140° to 145° Fahr. (60° to 62°·7 C.), and finally was heated up to 165° to 167° Fahr. (73°·8 to 75° C.).

	2 hrs. at 165° to 167° F. Per Cent.		6 hrs. at 165° to 167° F. Per Cent.	
Wt. of Extract,	70·25		70·55	
Draff, ...	21·58		20·71	
Glucose,......	39·06	= Starch 62·52	41 67	= Starch 62·51
Dextrine, ...	27·36		25·00	

The extract in the first case is considerable in amount; indeed, very much higher than any obtained in the English infusion process. We have no less than 39 of sugar and 27 of dextrine. In the second, where it was carried on for six hours at this range of temperature, the ratio of sugar and dextrine increases, that is to say, the dextrine diminishes and the sugar increases, though, by adding the two together, they are practically identical. If one-tenth is taken from the whole of the numbers representing the glucose, the remainder gives the amount of starch that it originally came from.

But there is a different ratio between the sugar and the dextrine. Therefore, by prolonging the temperature at this higher stage, the German brewer is correct in his idea of getting more sugar, because 2·36 of dextrine have been converted into 2·61 of sugar. Having thus proved the correctness of his idea, I proceeded next to test what would be the result if I were to take the extreme case, which of course no practical brewer ever uses, a temperature of 175° Fahr. (79°·4 C.). I took that as a crucial test. I took a sample of malt and heated it gradually during 60 minutes from the cold up to 175° Fahr. It was then kept at that excessively high temperature for a period of two hours, when the amount of sugar formed was 32 and the dextrine 30.

		(1.)	(2.)
Wt. of Extract, per cent.,................		69 70	69·10
Draff,	"	23·51	23·35
Glucose,	"	32·10	32·05
Dextrine,	"	30·29	30 60

Therefore, practically, the two results were identical. In other words, in that short time a ratio is obtained quite as high as is found in the English infusion method.

Thus, these two points being settled, viz., the advantage of a low initial temperature and the advantage of a high final temperature, I proceeded then to try to discover what would be the best way to arrange the mashing temperature. First of all, I heated malt from the cold up to 85° Fahr. (29°·4 C.) for one hour; I then carried it on from 85° to 140° Fahr. (60° C.) for one hour; and then for three hours it was kept at 140° Fahr. and then boiled. In the second series it was raised during the first hour from the cold up to 140° Fahr.; it was then allowed to remain for two hours at that temperature, and then it was raised very rapidly to 175° Fahr. (79°·4 C.), when it was boiled. In the third experiment it was raised in the first hour up to 140° Fahr.; it remained during the second hour at that temperature; and then in the third hour it was raised to 175° Fahr. (79°·4 C.).

	(1.) Per Cent.	(2.) Per Cent.	(3.) Per Cent.
Wt. of Ex.,	71·50	71·06	69·00
Draff, ...	21·70	22·35	22·61
Glucose,...	41·66	40·07	35·72
	=starch 62·59	=starch 62·51	=starch 60·76
Dextrine, ..	25·09	36·45	28·65

The first two yield practically the same results, making the same deduction as before by taking one-tenth from the determination of glucose, which will give us the starch from which it is derived. Those numbers added together are 62·59 and 62·51, showing practically the same amount of extract, whereas in the other case we have only 60·76 if the same deduction is made from the glucose. So that there has been in the rapid increase of temperature a very great falling off in the production of extract, and there has also been a great falling off in the ratio of the sugar to the dextrine. I think from these few experiments it may be seen, by comparing the numbers together, that the more gradually the temperature is raised the more perfect will be the extract, and the higher will be the sugar-forming ratio.

The limits of the varying ratios cannot exceed 2 of dextrine to 1 of sugar, or, on the other hand, 2 of sugar to 1 of dextrine, and besides depend on the varying conditions which may be taken as the functions of the experiment.

1. The ratios depend on the relative masses of starch and diastase. The more starch the less sugar will be formed in a given time.

2. It depends on the temperature of the infusions.

3. It also depends on the quantity of water employed. An infusion made with a small quantity of water will, in a given time, produce less sugar than when the infusion has more water, because the production of sugar from dextrine requires the obsorption with the molecule of so much water." (*Soc. of Arts Jour.* vol. xxii.)

Dr. GRAHAM proposes to increase the ratio of sugar by starting with a low initial temperature, in order that a large amount of the active principle diastase may be dissolved, and then raising the temperature of the mash up to 140° to 150° Fahr. (60° to 65°·5 C.), by adding hot "piece liquor," or passing steam into the underback by means of a coil. After digesting for some time at this temperature it should be raised to 165° Fahr. (73°·8 C.).

With high initial temperatures, as mashing is at present performed, the ratio of sugar is readily increased by adding cane sugar, which is for the most part converted into glucose by the diastase if added in the mash-tun; or it is converted into diastase if boiled with the wort by the free acids. On account of the large amount of albuminous matter contained in cane sugar, which tends to promote a putrescent fermentation, the cane sugar is commonly converted into grape sugar (invert sugar, dextri-glucose and levo-glucose) by dilute sulphuric acid. After conversion the free acid is thrown down by chalk, calcium sulphate (gypsum) being formed, a small percentage of which, if left with the sugar, is far from injurious to the wort.

The amount of dextrine may be augmented by adding thoroughly dried unmalted grain to the mash. Dextrine, when in large quantity after the worts are fermented, gives the soundness of flavour which is much esteemed in stout and porter, and certain kinds of ale.

C. O'SULLIVAN has made some interesting researches on the transformation products of starch, in the course of which he observed that from 100 parts of starch was formed 100 parts of a sugar, intermediate in molecular structure between grape sugar and starch; to this he has given the name of maltase. (*Chem. Soc. Journal*, vol. xxv.)

Maltase is white, soluble in water, but less soluble in alcohol than glucose; it withstands the action of diastase even when digested with it for a prolonged period. It is, however, readily converted by dilute sulphuric acid at the temperature of boiling water into ordinary glucose.

Having thus far spoken of the data and principles by which to regulate mashing at this stage of the process—for the first mash is the most important—the method of drawing off the wort, or "setting the tap," as it is called, together with the extraction of the portion of the goods still retained in the grains by the operation of sparging, or after-mashing, will next be considered.

In "setting the tap," most brewers recommend that the goods should be drawn off at the same degree as is indicated at the conclusion of the mashing, whatever the variety of malt worked upon. Those who may not be very conversant with the real nature of the subject, and may have doubts as to the quality of the malt, its newness, hardness, weight, slackness, or dryness (all of which require a variation of the heat, or of the quantity of liquor), if they are already acquainted with the final heat of the first mash of a good operation, have only to raise the tap to this point, and copy it in their subsequent mashing.

The first mash being completed, and the underback wherein the sweet worts are received being thoroughly clean, the tap is turned on gently at first, and afterwards more quickly, till the liquor runs half bore. Unless great care be exercised the worts will not flow off bright and clear as they should do, and particles of the more finely divided grain, which are sometimes productive of inconvenience in the succeeding operations, will percolate through.

If the process has been successful the wort will be of the same shade of colour as the malt employed; it should have a tough and close head of a silvery whiteness, passing, when examined in the vessel, to a delicate cream on the surface. It should be full, effervescing, and fine flavoured, considerably more so than the succeeding extract or after mash, in consequence of the more mucilaginous and resinous parts of the grist not being abstracted. When the heat of the mash is too high, it is observed that the silvery white head has a tinge of brown, and that this colour is deeper in proportion to the greater elevation of the mash above the proper degree. Again, if the heat be too low, the head is less close, firm, bright, and lively in flavour. With very low heats the head will not stand, but flies off instantly, and the taps are thick and muddy. This kind of wort, on being exposed to the air, readily enters into decomposition and turns acid.

When the whole of the extract has been drained off, the proper quantity of liquor to be used in removing the residuary portion, which is retained mechanically by the grist, as well as any starch which may still be present, is turned on. If the preceding details have been carefully attended to, the quantity of the starch will be inconsiderable. Many persons employ from three-eighths to one-half the quantity of water taken from the first extract, and add it at 185° Fahr. (85° C.), or 10° Fahr. (5°·5 C.) over that at which the first mash was made, and treat the goods as in the first mash, except that the time is only a quarter or one-half that allowed to the first. The precautions which have already been mentioned should be observed in setting the tap; and the worts should be conveyed to the boiler together with the first portion.

By an economical disposal of the temperature and duration of the mash, as well as the proportion of the liquor taken, the residual starch in the grains will be inappreciable; but when, as in many cases, the operations are conducted in a haphazard, unscientific, and often in an irrational way, there sometimes remains after the second mash as much as from 8 to 10 lbs. per barrel extract, and it even happens that this is not wholly removed by a third watering. This product, however, is coarse and ill-flavoured, owing to the great proportion of bitter resin and mucilage intermixed with it, and which hitherto had remained in the grains, the temperature not having been retained at that degree at which the diastase could exert its influence in saccharizing these substances. In order to avoid the accumulation of such degenerating constituents in the third and fourth mash, the heat should be 10° to 12° Fahr. (5°·5 to 6°·6 C.) higher in the second than in the first mash, if products are run into the boiler as the strong wort; if three mashings are to be made for the same, a difference of 5° or 6° (2°·7 to 3°·3 C.) in each is sufficient, making the final one at 160° Fahr. (71°·1 C.).

It is to be observed that the custom of mashing so repeatedly is at variance with the opinions of most chemists who have investigated the subject of brewing.

Another method is also adopted for abstracting the residuary matters in the grist, after the first mash is completed, which is called "sparging," from the circumstance that the liquid is sprinkled on the goods from numerous outlets. It is said to be very beneficial in its results, particularly when the whole of the wort is intended for the strong or the better quality of beer. The method of sparging is as follows:—When the tap has been set for drawing off the first wort, hot liquor, of the same temperature as the preceding mash, is sprinkled on the malt from a machine constructed thus: a perforated tube is laid upon a bar, the two being placed horizontally in the tun, and resting upon a pin in the centre, over these a receiving vessel is placed to supply the tube with water. The perforations extend to the whole length of the two or three arms of the tube, so that the liquid flows out horizontally, but in opposite directions; and through the effect of the force of this efflux, together with the centrifugal motion communicated by the current coming from the receiving vessel, the pipe is kept rotating, and the liquor is dispersed equally over the goods. Some brewers, instead of the tube, use a cover, which they place over the liquor, and direct the stream upon it; the first method seems, however, to be more efficient.

Many persons do not set the sparger till one-fourth, one-half, or even three-fourths of the strong extract has been drawn off; but when the liquid is sprinkled on gently—as it must be from the perforated tubes—there need be no apprehension of the wort being too dilute; and the good which is done by displacing the quantity of the stronger mash imbibed by the malt, as also by exhausting from the grist the residual saccharine matter, without taking up the resinous constituents, is an undoubted recommendation; besides which, when the chief part of the first mash is drawn off before the sparging, the grains accumulate in too dense a layer on the bottom.

To many brewers whose routine of working is based on old established practice this mode may appear ruinous, as their after mashings contain 6 to 10 lbs. of extract per barrel, which are calculated to be as valuable as an equal proportion of the first wort; but if a proper course of mashing be adopted, the whole of the valuable constituents will be taken up in the first wort, and what remains embedded in the grist can be removed by washing or sparging, in the manner which has just been described. A dense and valuable wort will be thus obtained, and the cost of subsequent concentration will be much lessened.

It is necessary to have the sparging continued without intermission, till the whole of the soluble matters is removed, using only as much liquor as is necessary to make up the proper lengths.

The grains left after mashing, or when the whole of the starch has been removed, are used to feed swine and cattle. They contain gum, some of the nitrogenous constituents of the barley, together with a certain amount of cellulose, which is as nourishing to animals as an equivalent weight of the original unmalted grain. In addition to these there is a further quantity of mucilage, which will contribute in the animal economy to effect the same purposes and ends as starch.

SACCHAROMETRY.—The brewer estimates the quantity of sugar in his wort by its density. The knowledge of the gravity of the beer after fermentation, so as to ascertain the quantity of spirit and saccharine matters contained in it, is also of importance.

Table by Dr. Ure showing the quantity of Sugar in Pounds Avoirdupois contained at successive degrees of Specific Gravity, at 60° Fahr. (15·°5 C.).

Specific Gravity.	Lbs. per Gallon.	Extract by weight in 100.	Specific Gravity.	Lbs. per Gallon.	Extract by weight in 100.	Specific Gravity.	Lbs. per Gallon.	Extract by weight in 100.	Specific Gravity.	Lbs. per Gallon.	Extract by weight in 100.
1·000	0·0000	·0000	1·076	1·9928	·1828	1·152	4·0342		1·228	6·0642	
1·001	0·0255	·0026	1·077	2·0197	·1851	1·153	4·0611		1·229	6·0925	
1·002	0·0510	·0051	1·078	2·0465	·1873	1·154	4·0880		1·230	6·1205	
1·003	0·0765	·0077	1·079	2·0734	·1896	1·155	4·1148		1·231	6·1474	
1·004	0·1020	·0102	1·080	2·1006	·1918	1·156	4·1319		1·232	6·1743	
1·005	0·1275	·0128	1·081	2·1275	·1941	1·157	4·1588		1·233	6·2012	
1·006	0·1530	·0153	1·082	2·1543	·1963	1·158	4·1857		1·234	6·2280	
1·007	0·1785	·0179	1·083	2·1811	·1985	1·159	4·2128		1·235	6·2551	
1·008	0·2040	·0204	1·084	2·2080	·2007	1·160	4·2502		1·236	6·2822	
1·009	0·2295	·0230	1·085	2·2359	·2029	1·161	4·2771		1·237	6·3093	
1·010	0·2550	·0255	1·086	2·2627	·2051	1·162	4·3040		1·238	6·3362	
1·011	0·2805	·0280	1·087	2·2894	·2073	1·163	4·3309		1·239	6·3631	
1·012	0·3060	·0306	1·088	2·3161	·2095	1·164	4·3578		1·240	6·3903	
1·013	0·3315	·0331	1·089	2·3438	·2117	1·165	4·3847		1·241	6·4152	
1·014	0·3570	·0356	1·090	2·3710	·2139	1·166	4·4115		1·242	6·4401	
1·015	0·3825	·0381	1·091	2·3987	·2161	1·167	4·4383		1·243	6·4650	
1·016	0·4180	·0406	1·092	2·4256	·2183	1·168	4·4652		1·244	6·4902	
1·017	0·4335	·0431	1·093	2·4524	·2205	1·169	4·4923		1·245	6·5153	
1·018	0·4590	·0456	1·094	2·4792	·2227	1·170	4·5201		1·246	6·5402	
1·019	0·4845	·0481	1·095	2·5061	·2249	1·171	4·5460		1·247	6·5651	
1·020	0·5100	·0506	1·096	2·5329	·2270	1·172	4·5722		1·248	6·5903	
1·021	0·5351	·0531	1·097	2·5598	·2292	1·173	4·5983		1·249	6·6152	
1·022	0·5602	·0555	1·098	2·5866	·2314	1·174	4·6242		1·250	6·6402	
1·023	0·5853	·0580	1·099	2·6130	·2335	1·175	4·6505		1·251	6·6681	
1·024	0·6104	·0605	1·100	2·6404	·2357	1·176	4·6764		1·252	6·6960	
1·025	0·6355	·0629	1·101	2·6663	·2378	1·177	4·7023		1·253	6·7240	
1·026	0·6606	·0654	1·102	2·6921	·2400	1·178	4·7281		1·254	6·7521	
1·027	0·6857	·0678	1·103	2·7188	·2421	1·179	4·7539		1·255	6·7800	
1·028	0·7108	·0703	1·104	2·7416	·2443	1·180	4·7802		1·256	6·8081	
1·029	0·7359	·0727	1·105	2·7704	·2464	1·181	4·8051		1·257	6·8362	
1·030	0·7610	·0752	1·106	2·7961	·2486	1·182	4·8303		1·258	6·8643	
1·031	0·7861	·0776	1·107	2·8227	·2507	1·183	4·8554		1·259	6·8921	
1·032	0·8112	·0800	1·108	2·8485	·2529	1·184	4·8802		1·260	6·9201	
1·033	0·8363	·0825	1·109	2·8740	·2550	1·185	4·9051		1·261	6·9510	
1·034	0·8614	·0849	1·110	2·9001	·2571	1.186	4·9300		1·262	6·9822	
1·035	0·8866	·0873	1·111	2·9263	·2593	1·187	4·9552		1·263	7·0133	
1·036	0·9149	·0897	1·112	2·9522	·2614	1·188	4·9803		1·264	7·0444	
1·037	0·9449	·0921	1·113	2·9780	·2635	1·189	5·0054		1·265	7·0751	
1·038	0·9768	·0945	1·114	3·0045	·2656	1·190	5·0304		1·266	7·1060	
1·039	1·0090	·0969	1·115	3·0304	·2677	1·191	5·0563		1·267	7·1369	
1·040	1·0400	·0993	1·116	3·0563	·2698	1·192	5·0822		1·268	7·1678	
1·041	1·0653	·1017	1·117	3·0821	·2719	1·193	5·1080		1·269	1·1988	
1·042	1·0906	·1041	1·118	3·1080	·2740	1·194	5·1341		1·270	7·2300	
1·043	1·1159	·1065	1·119	3·1343	·2761	1·195	5·1602		1·271	7·2601	
1·044	1·1412	·1089	1·120	3·1610	·2782	1·196	5·1863		1·272	7·2902	
1·045	1·1665	·1113	1·121	3·1871	·2803	1·197	5·2124		1·273	7·3204	
1·046	1·1918	·1136	1·122	3·2130	·2824	1·198	5·2381		1·274	7·3506	
1·047	1·2171	·1160	1·123	3·2399	·2845	1·199	5·2639		1·275	7·3807	
1·048	1·2424	·1184	1·124	3·2658	·2865	1·200	5·2901		1·276	7·4109	
1·049	1·2687	·1207	1·125	3·2916	·2886	1·201	5·3160		1·277	7·4409	
1·050	1·2940	·1231	1·126	3·3174	·2907	1·202	5·3422		1·278	7·4708	
1·051	1·3206	·1254	1·127	3·3431	·2927	1·203	5·3681		1·279	7·5007	
1·052	1·3472	·1278	1·128	3·3690	·2948	1·204	5·3941		1·280	7·5307	
1·053	1·3738	·1301	1·129	3·3949	·2969	1·205	5·4203		1·281	7·5600	
1·054	1·4004	·1325	1·130	3·4211	·2989	1·206	5·4462		1·282	7·5891	
1·055	1·4270	·1348	1·131	3·4490	·3010	1·207	5·4720		1·283	7·6180	
1·056	1·4536	·1372	1·132	3·4769	·3030	1·208	5·4979		1·284	7·6469	
1·057	1·4802	·1395	1·133	3·5048	·3051	1·209	5·5239		1·285	7·6758	
1·058	1·5068	·1418	1·134	3·5326	·3071	1·210	5·5506		1·286	7·7048	
1·059	1·5334	·1441	1·135	3·5605	·3092	1·211	5·5786		1·287	7·7331	
1·060	1·5600	·1464	1·136	3·5882	·3112	1·212	5·6071		1·288	7·7620	
1·061	1·5870	·1487	1·137	3·6160	·3132	1·213	5·6360		1·289	7·7910	
1·062	1·6142	·1510	1·138	3·6437	·3153	1·214	5·6651		1·290	7·8201	
1·063	1·6414	·1533	1·139	3·6716	·3173	1·215	5·6942		1·291	7·8482	
1·064	1·6688	·1556	1·140	3·7000	·3193	1·216	5·7233		1·292	7·8763	
1·065	1·6959	·1579	1·141	3·7281	·3214	1·217	5·7522		1·293	7·9042	
1·066	1·7228	·1602	1·142	3·7562	·3234	1·218	5·7814		1·294	7·9321	
1·067	1·7496	·1625	1·143	3·7840	·3254	1·219	5·8108		1·295	7·9600	
1·068	1·7764	·1647	1·144	3·8119	·3274	1·220	5·8401		1·296	7·9879	
1·069	1·8033	·1670	1·145	3·8398	·3294	1·221	5·8680		1·297	8·0150	
1·070	1·8300	·1693	1·146	3·8677	·3314	1·222	5·8962		1·298	8·0148	
1·071	1·8571	·1716	1·147	3·8955	·3334	1·223	5·9242		1·299	8·0719	
1·072	1·8843	·1738	1·148	3·9235	·3354	1·224	5·9523		1·300	8·1001	
1·073	1·9116	·1761	1·149	3·9516	·3374	1·225	5·9801				
1·074	1·9385	·1783	1·150	3·9801	·3394	1·226	6·0081				
1·075	1·9653	·1806	1·151	4·0070		1·227	6·0361				

Reference has already been made to the means whereby the worts may be tested, and the amount of saccharine matter ascertained, by the specific gravity of the liquor as shown by the saccharometer; but as the liquor at this stage is usually between 150° and 160° Fahr. (65°·5 to 71°·1 C.), the indication which it gives is only the apparent density, since, by expansion, the bulk of the solution is considerably increased; and therefore the amount of solid extractive matter, in any given volume of the liquor, is much less than what the same bulk would show at 60° Fahr. (15°·5 C.), the barometer being at 29·5 or 30 inches.

A variety of saccharometers are in use; the one chiefly employed in the trade, and by the Excise, is that constructed by R. B. Bate. This instrument shows the value of wort and low wines, the excess in the weight of a beer barrel of wort above that of water, the solid extract or the true pounds weight per beer barrel, beer gallon, wine gallon, and imperial gallon, and the proportion of solid extract by weight. It is usually made of metal, has five floats answering to the different strengths of the wort, and one to indicate which of the poises will suit for each occasion, mostly on the same plan as Sikes' alcoholometer. (See Alcohol.). The instrument is accompanied by a book, wherein are copious explanations and directions for using it, together with tables of gravity and strengths per barrel for every degree of specific gravity, from ·995 to 1·150, and also every alternate degree of temperature, from 50° to 150° Fahr.

Dr. Ure, who in 1830 experimented on this subject, states that the specific gravity of the solid dry extract of malt is 1·264, and the specific volume 0·7911, that is, ten pounds of it will occupy the volume of 7·911 of water. When this extract is dissolved in its own weight of water, the density of the resulting liquid, by calculation, ought to be 1·1166, whereas, by experiment, it proved to be 1·216, thus showing that a considerable condensation of volume had taken place in the act of combination with the water.

The following table, showing the relation between the specific gravity of the solutions of malt extract and the quantity of matter they contain, illustrates the above statement:—

Malt Extract. Water.	Malt Extract in 100.	Sugar in 100.	Specific Gravity.
600 + 600	50·00	47·00	1·2160
600 + 900	40·00	37·00	1·1670
600 + 1200	33·33	31·50	1·1350
600 + 1500	28·57	26·75	1·1130
600 + 1800	25·00	24·00	1·1000

Regarding the saccharometric tables constructed by Bate and others on solutions of sugar, and not upon those of extract of malt, Ure remarks that they agree pretty well with the former, but differ materially from the latter.

On page 299 is given Dr. Ure's saccharometric table for a simple syrup.

Apart from the foregoing consideration, there is an important circumstance which must be taken into account in ascertaining the gravity, namely, the different expansions of bodies at various degrees of temperature, from 32° Fahr. (0° C.) to their boiling point. When many liquids are heated from 32° Fahr., or their point of greatest density, to 212° Fahr. (100° C.), considerable difference is observed in this respect; for instance, the dilatation of alcohol is much greater than that of water, and this again than mercury, and so of numerous other liquids. The amount of expansion of different liquids in passing through one hundred and eighty degrees Fahrenheit (100° C.), that is, from 32° to 212° Fahr., is found by experiment to be—

Alcohol,	$\frac{1}{9}$	Oil of turpentine,	$\frac{1}{14}$
Nitric acid,	$\frac{1}{9}$	Sulphuric acid,	$\frac{1}{17}$
Fixed oils,	$\frac{1}{12}$	Water,	$\frac{1}{23}$
Ether,	$\frac{1}{14}$	Mercury,	$\frac{1}{55}$

It may be well to illustrate the meaning of the above by showing the difference in volume of water from 32° to 212°, as given by several chemists who have investigated the subject.

There is one remark, however, which is deserving of being made, for the sake of those who may not be conversant with such subjects, namely, that heat communicated to the bottom of liquids is readily diffused through the whole body; not, however, by radiation, as is the case with solids, but by the dilatation of the inferior particles, which renders them specifically lighter than those above them, on which account they ascend, their place being occupied by other globules; these, again, receiving warmth and ascending like the preceding. Thus, by the constant exposure of fresh portions of water to heat, and the motion produced in the liquor by their rarefaction, the whole bulk is brought to that degree beyond which any further application of heat would destroy the limits within which its density and liquidity remain, and the fluid would become a vapour or gas. But when the heat is applied to the surface of a liquid the supernatant particles only receive the rays, these expand, are rendered lighter, and continue to float upon the denser, which are consequently only very gradually warmed. This slowness of acquiring heat from the surface led Rumford to deny that water, or fluids generally, had any power of conducting it; it is, however, now known that liquids do conduct heat, though in a degree far inferior to solids.

Science has converted this phenomenon to highly beneficial uses in many departments of industrial progress. The thermometer, with all its inestimable benefits, is based upon it, and at the present day the application of expansion of bodies by heat to the requirements of manufactures, trade, and navigation, commands no small consideration in contributing to the wealth of nations.

According to Kopp, water expands when heated from 32° to 212° Fahr., 0·042986 of its volume, as will be seen from the annexed table of the expansion of water from the freezing to the boiling temperature, the volume at 0° C., or 32° Fahr., being taken as unity:—

Temp. Cent.	Temp. Fahr.	Volume.	Temp. Cent.	Temp. Fahr.	Volume.
0°	32°	1·000000	21°	69·8°	1·001776
1	33·8	0·999947	22	71·6	1·001995
2	35·6	0·999908	23	73·4	1·002225
3	37·4	0·999885	24	75·2	1·002465
4	39·2	0·999877	25	77·0	1·002715
5	41·0	0·999883	30	86·0	1·004064
6	42·8	0·999903	35	95·0	1·005697
7	44·6	0·999938	40	104	1·007531
8	46·4	0·999986	45	113	1·009541
9	48·2	1·000048	50	122	1·011766
10	50·0	1·000124	55	131	1·014100
11	51·8	1·000213	60	140	1·016590
12	53·6	1·000314	65	149	1·019302
13	55·4	1·000429	70	158	1·022246
14	57·2	1·000556	75	167	1·025440
15	59·0	1·000695	80	176	1·028581
16	60·8	1·000846	85	185	1·031894
17	62·6	1·001010	90	194	1·035397
18	64·4	1·001184	95	203	1·039094
19	66·2	1·001370	100	212	1·042986
20	68·0	1·001567			

The preceding table shows the degree of contraction which water undergoes when heated from 32° Fahr. (0° C.), to its point of greatest density, which is stated as 39·2° Fahr. (4° C.). From this point to the normal temperature of 60° Fahr. (15°·5 C.), the expansion of a volume of water is 0·000894, and from this to 158° Fahr. (70° C.), ·021475 of its original volume. Now, a given bulk of liquid, having solid bodies, such as mineral or organic salts, dissolved in it, does not increase or contract in the same proportion when heated from 32° to 212° Fahr. (0 to 100° C.), as does pure water, in consequence of the solid matter not being so expansible as the liquid. From this it follows that dense worts will not dilate or contract so much as those which are more dilute. On examining worts of high temperatures, it is necessary to find and allow for the increase of weight consequent upon the contraction of any given bulk of liquid, when cooled from a higher to a lower degree of heat.

According to Bate's tables, the allowance which should be made for every ten degrees between the normal points, 60° and 150° Fahr. (15°·5 to 65°·5 C.), is as follows:—

Saccharometric Gravity.	70°	80°	90°	100°	110°	120°	130°	140°	150°	Sum.
10	1·0	1·2	1·5	1·7	1·9	2·1	2·3	2·5	2·8	17·0
50	1·2	1·4	1·6	1·8	2·1	2·3	2·5	2·7	3·0	18·6
100	1·4	1·6	1·8	2·0	2·2	2·5	2·7	2·9	3·2	20·3
150	1·6	1·8	2·0	2·2	2·4	2·7	2·9	3·2	3·4	22·2

The subjoined table by Bate will answer the purposes of the ordinary brewer; and where the corresponding degree does not occur, a correct fraction may be attached at an average, founded on the following facts. When a liquid, the specific gravity of which is 1·000 at 60° Fahr., is heated to 78° Fahr. (25°·5 C.), the instrument will sink two divisions below the true gravity as found at 60° Fahr. (15°·5 C.), and if the temperature be elevated to 93° Fahr. (33°·8 C.), it will sink four divisions, and so on. Any solution, therefore, which has been heated to these points, and tested with the hydrometer or saccharometer, will manifest a much higher density when cooled down to 60° Fahr. (15°·5 C.), the normal standard temperature; thus, if there be three liquids at the temperatures of 124°, 92°, and 79° (51°·1, 33°·3, and 25°·5 C.), and the instrument be dropped into them, it will sink in the first ten, in the second eight, and in the third six divisions, lower than it would in the same were they cooled down to 60° Fahr. (15°·5 C.); hence, when testing the liquors heated to these degrees, it is necessary to add the numbers ten, eight, six, &c., to the apparent densities, in order to find the real gravity at the standard of 60° Fahr. (15°·5 C.).

Specific Gravity at 60° Fahr.	Apparent gravities giving the same density at the accompanying heats as the first column at 60°.									
	Ap. sp. gr.	Degrees.	Ap. sp. gr.	Degrees.	Ap. sp. gr.	Degrees.	Ap. sp. gr.	Degrees.	Ap. sp. gr.	Degrees.
1·000	0·998	79 00°	0·996	93·00°	0·994	105·00	0·992	115·50°	0 990	125·20°
1·010	1·008	78·00	1·006	92·00	1·004	104·00	1 002	114·50	1·000	124·00
1·020	1 018	78 00	1·016	91·33	1·014	103·00	1·012	113·50	1·010	122·80
1.030	1·028	77·33	1·026	90·66	1·024	102·50	1·022	112·50	1·020	122·00
1·040	1·038	76·66	1·036	90·00	1·034	101·50	1·032	111 50	1·030	120·80
1·050	1·048	76·00	1·046	89·33	1 044	100 66	1·042	111·00	1·040	120·00
1·060	1·058	76·00	1·056	88·66	1·054	100·00	1·052	110·00	1·050	118·80
1·070	1·068	75·33	1 066	88·00	1·064	99·00	1·062	109·00	1·060	118·00
1 080	1·078	74·66	1·076	87 33	1·074	98·00	1·072	108·00	1·070	116·80
1·090	1·088	74·66	1·086	86·66	1·084	97·50	1·082	107·00	1·080	116·00
1·100	1·098	74·00	1·096	86·00	1·094	96·50	1·092	106·50	1·090	114 80
1·110	1·108	74·00	1·106	85·50	1·104	96·00	1·102	105·50	1·100	114·00
1·120	1·118	73·50	1·116	85·00	1·114	95·50	1·112	104·50	1·110	113·20
1·130	1·128	73·33	1·126	84·50	1·124	94·50	1·122	104·00	1·120	112·40
1·140	1·138	73·00	1·136	84·00	1·134	94·00	1·132	103 20	1·130	111·40
1·150	1·148	72·66	1·146	83·50	1·144	93·50	1·142	104·40	1·140	110·80

The following is a theorem for reducing the gravities of hot worts. To unity, or 1, representing the standard of water, add 0·1 for every twenty-five points of gravity indicated by the instrument, and 0·01 for each degree of temperature above 60, and multiply the sum by ten times the latter number for the correction.

Example 1.—Let the apparent density be 6, and the temperature 92°, then (1 + ·32) × 3·2 = 4·224, which, added to the original 6, gives 10·224.

Example 2.—Apparent gravity 27, temperature 124°.

Here (1·1 + ·64) × 6·4 = 1·74 × 6·4 = 11·136, and 11·136 + 27 = 38·136, results which agree with those of Bate.

Boiling.—Boiling of the worts is avowedly practised with the intent of removing the excess of nitrogenous matter; for if this were permitted to remain it would undergo the putrid fermentation and completely destroy the whole product: but boiling is also reputed to give to the liquor a pleasant flavour, and render it more wholesome. The most satisfactory recommendations in its favour, however, are that it diminishes the liability to acidity by expelling the contained air. When those matters which are subject to acetification are in a measure excluded from the atmosphere, the liquor remains sound for a long time.

Boiling is also requisite for the expulsion of the excess of liquor used in the mashing, as well as for the transformation of any starch which might still remain intact into glucose and dextrine.

There is a further important object for which the worts are boiled, namely, the extraction of the valuable bitter and aromatic principles of the hops, whereby the flavour of the liquor is improved and an agreeable aroma imparted to it.

The hops not only impart a bitter aromatic taste, but also a keeping quality, as they counteract the natural tendency of the beer to become sharp—an effect partly attributable to the precipitation of the albumen and starch by their resin and tannic acid, and partly to the anti-fermentable properties of their lupulin and other constituents.

Various opinions have been set forth regarding the necessity, the efficacy, and the injuriousness of boiling; generally speaking, the idea is that from the manner in which it is usually conducted it acts prejudicially, inasmuch as by it the most prized material of the hops—the odoriferous oil—is dissipated, and too much of the disagreeable principle and tannin extracted, so that the bitterness and astringency become too powerful. Those who condemn boiling altogether should study its anti-putrescent effects, especially where albuminous and other substances, analogous to those in the extract, are present. Boiling has the effect of expelling air from the liquid, and coagulating the albumen; the matter being thus excluded from air or oxygen, may be preserved without undergoing putrefaction.

It is well known that nitrogenous substances, which will otherwise very readily putrefy, may be retained for a considerable period in a wholesome state by expelling air and keeping them afterwards in exhausted receivers. By abstracting the air contained in the wort, and guarding against its reabsorption by keeping the liquor in exhausted vessels, it may be preserved during any length of time without giving rise to acid products. The same result may be attained even in presence of air by retaining it at a low degree of cold; but upon the application of a heat ranging from 70° to 90° Fahr. (21° to 32°·2 C.), with exposure to the influence of the air, the oxidation of the compounds present follows, and finally acetic acid, with the products usually formed in putrefying bodies, results. These observations strongly support Pasteur's theory of fermentation by accession of germs.

Were there only saccharine matter present, the liquor might be preserved a length of time at any temperature, without risk of the acidification of the worts occurring; but the proneness of the nitrogenous impurities to *eremacausis* (Liebig's term for oxidation, slow combustion, *anglice*, decay) opens the way for the mucilage and sugar to pass partly into the lactic and partly into the vinous fermentation, and then, by a further state of chemical decomposition, into acetic acid, when it is needless to say the whole of the materials are spoiled.

Thus far in reference to the keeping of the worts and their protection from decomposition by boiling; its immediate effect will now be taken into account.

Evidently this operation tends to, or has for its object, the removal of albumen and any other matters which, if permitted to remain in the wort, would readily absorb oxygen on being left in contact with the air, and cause the chemical changes which brewers have so much reason to apprehend; but in effecting this purpose it is argued that, besides a valuable portion of the glucose and dextrine being abstracted, the essential oil of the malt is almost entirely volatilized in consequence of the long boiling at the high temperature at which this is done. That portions of the sugar are removed, or rendered unavailable to some extent, cannot be doubted; for it is well known that when vegetable extracts, and indeed most organic compounds, some of which are as permanent in their nature as sugar, are boiled for a long time, a gelatinous substance, similar in character to woody fibre, forms in the solution at the expense of a portion of the compound, which must have suffered decomposition. Such is the case in the open copper of the brewer, especially when the air is not excluded; but as to the oil inherent in the malt being dissipated, this is a new and gratuitous supposition which has no foundation; for the oil of the grain in its natural state is not expelled at a temperature of 212° Fahr. (100° C.).

From the above considerations the correct conclusion to be drawn appears to be, that were it not for the necessity of removing the nitrogenous matters, the boiling of the worts might be dispensed with. It has been urged that though distillers do not boil their worts, yet the attenuation in the succeeding fermentation is very complete. This must be granted; but it should be borne in mind that they immediately remove the spirit from the gross nitrogenous products by distillation, lest the latter, if permitted to remain with it, should change it into acetic acid by regular and well-defined processes which have been already discussed. (See Acetic Acid). It is true also that the generation of alcohol in the liquor during fermentation, and the protracted way in which this is carried out in some varieties of ale breweries, would, in the first instance, cause the precipitation of the albumen and mucilage; but portions might still remain, and though the quantity might be apparently insignificant, yet under the various effects of temperature and other causes it would prove destructive, if not removed either during the fermentation in the shape of yeast, or before fermentation by boiling; or altogether excluded by a better system of mashing.

It is well known among brewers, if not in theory at least in effect, that beers retaining much nitrogenous substances, however richly they may be hopped and otherwise carefully prepared, cannot be preserved in warm climates; neither will they retain their qualities at home when, on tapping, the air gets access to them, unless the temperature of the atmosphere be about 45° Fahr. (7°·2 C.), or lower; for as soon as the air is admitted, if the temperature is above 60° or 70° Fahr. (15°·5 to 21°·1 C.), the oxidation of the gluten commences, and the heat rises in consequence; the reaction set up causes the formation of a further quantity of alcohol from the sugar, and changes the alcohol already formed into acetic acid.

Were the fermentation of the worts carried on at a low temperature, as in Bavaria, then the excess of the albuminous and other analogous bodies might be allowed to remain without the least fear of their causing putrefaction and subsequent acetification, and there would be no need of removing any portion of them by the preparatory operation of boiling.

Many brewers allege that their only reason for boiling is the extraction of the lupulin of the hop, and to effect this the ebullition is continued at no small expense and trouble for a considerable period. Others, on the contrary, denounce boiling as being, next to acetic acid, the bane of the brewery; but reason affirms, and time and experience attest, that there is a mean which affords security from the bad effects of either extreme.

Vegetable albumen is insoluble in water at a temperature approaching ebullition, and the expansion of the air caused by the imbibition of the heat dissipates it as soon as it reaches 212° Fahr. (100° C.); the further continuation of the heat after this point is gained must evidently have in view the agglutination of the finely-divided insoluble particles already precipitated; but to prolong it more than fifteen minutes seems unreasonable, and is certainly prejudicial, inasmuch as portions of the saccharine matter will be decomposed, as before stated. The criterion which appears to regulate the time of the boiling in breweries is the formation of a mass of insoluble or precipitated matter. In place of this, the great object should be the coagulation of the particles, and their falling to the bottom in the copper should be less regarded; for during the fermentation, whilst the yet soluble portion of gluten is becoming insoluble by feeding the yeast, these will be carried away mechanically in the eviscerated matter, or deposited during the cleansing, without proving injurious to the liquor.

From these considerations it follows that the worts should not be subjected to a protracted ebullition, with the view of removing the albuminous ingredient, it being sufficient merely to render it insoluble; and whether it remains in the copper, is retained in the hop-back, or passes along to the fermenting tun to be there finally and entirely removed with the barm, is a matter of no very great moment, since it is deprived of the possibility of decomposing by oxidation within this period.

It will be observed from the description already given of the hop, that its efficacy as to flavour and bitterness depends upon the volatile aromatic oil and the resin which it contains; it likewise communicates astringency in consequence of the tannic acid or tannin which it yields. The gum and other matters removed from the flowers by water are of no very great interest.

If hops be macerated with water and subjected to distillation, the whole, or chief portion, of the oil will very readily pass over into the receiver, leaving the solution in the retort almost entirely destitute of smell, but retaining the bitterness and astringency of taste in a very marked degree. This is well known to brewers generally; and those who show some regard to facts, curtail in practice the time of boiling, or make such deviations from the old-established routine as seem to them best adapted for the retention of the aroma.

Were the "condition" or valuable portion of the hop extracted in such a way as to retain the volatile aromatic oil, there is no doubt the beer would be greatly improved in quality. Tizard made an effort in this direction by introducing his "hop-converter," by the use of which, he says, the most agreeable constituents are abstracted for the better kinds of ale, and if it be deemed necessary the coarser portions may be used up in the inferior products. His method of doing this is by converting the lower part of the under-back into a hop-back, by inserting a perforated floor above the true bottom of the mash-tun. Upon the solid bottom of this new hop-back, or above it, but beneath the perforated plates, coils of tubing are laid, through which steam from an adjacent boiler is forced, and for facility of management there should be a steam-cock fixed in the entrance pipe to regulate the flow of vapour. The hops, after being thoroughly broken up, are laid evenly upon the perforated floor of the hop-converter, four hours before setting the tap, and as much hot water poured upon them from the heated liquor-back as will effect their saturation completely; they are then left to digest for one hour, after which the steam is passed through the convoluted pipe till the mixture has attained a temperature of 200° Fahr. (93°·3 C.), retaining it at this point for the remainder of the time till the setting of the tap. The steam is then turned off, and the wort let in upon the hops to the depth of 6 inches, when the pump is worked, and the goods discharged upon the coolers, taking the precaution to preserve the depth of 6 inches of liquor upon the hops during the time of racking and sparging. In this way, Tizard asserts, the value of the hop is retained; for the temperature during the digestion being 12° Fahr. (5°·5 C.) below the boiling point, very little vapour is expelled; but it serves to withdraw the whole of the valuable constituents, and the worts being in contact with the hops during the exhaustion of the grist with the hot liquor—all the taps being open—the whole of their extract and essence is carried off in the goods.

In operating thus, it will be seen that Tizard discards boiling the worts, but this is in some measure compensated for by raising the heat of the mash towards the time of drawing off the wort to a temperature of 200° Fahr. (93°·3 C.), or upwards, by means of an attemperator, for the purpose of coagulating the albumen, and maintaining this degree for twenty minutes or half an hour, as may seem best. Were the whole of the starch already converted into sugar, there is little doubt but that the method of steam boiling would be most suitable and economical. Steam boiling also supplants the several costly requisites which enter into the brewer's stock of apparatus and material, and thus effects a saving in the plant, while the work performed is, by proper management, as effectual and more satisfactory than when accomplished by the various coppers and furnaces.

Other contrivances have of late been resorted to for dispensing with boiling the worts and hops together, to obviate the danger of losing the aromatic constituents. Among these the process of Newton, of London, may be instanced, in which an extract of hops is prepared, which is then sold to the brewer.

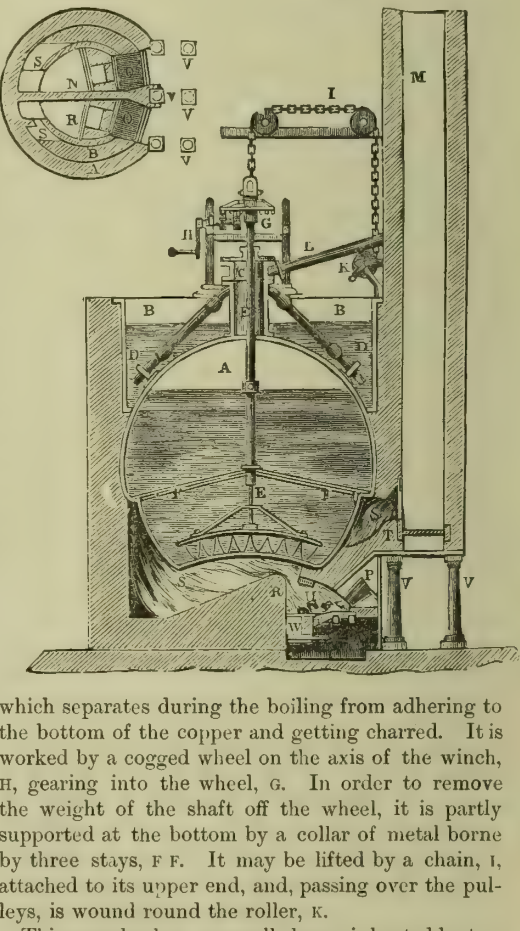
The same method has been followed for some time in France and some parts of the Continent, but the brewers in the United Kingdom do not appear to appreciate it. Newton's mode of preparing the extract is as follows:—After having dried the hops at a low heat till they become so brittle as to be easily pulverized, the powder is passed through a coarse sieve for the purpose of retaining any stalks or pieces of wood which might be accidentally present; it is then put into a close vessel, and strong spirit of wine or alcohol poured over it till the whole becomes charged; this mixture is allowed to repose for twenty-four hours, after which the alcoholic tincture is drawn off into an appropriate receiver, and the residual powder washed as long as any extract is obtained.

The next course is to distil off the alcohol, by which means the oil and resinous body are left, mixed with a little water, which is also dispersed, first on the sand-bath and finally on the water-bath. The aqueous washings of the powdered leaves, which contain almost the whole of the resin, are also evaporated till the water is expelled; and when this is accomplished, and while the resinous matter is still warm, the oily body procured from the alcoholic tincture is added, and intimately mixed with it. One pound of this extract is said to be as efficacious as 3 lbs. of flowers.

Boiling Coppers.—The "liquor" for mashing has to be heated, and the wort has to be boiled; and although the mode of heating the liquor should properly be described before mashing, yet heating the liquor and boiling the wort being frequently done in the same manner, both are treated under the same heading. The usual temperature for heating is about 170° Fahr. (76°·6 C.), but the liquor is generally allowed to cool down to the required temperature. Formerly both liquor and wort were boiled in a brewing copper placed over a fire, but of late years steam has been largely used, especially for heating liquor. The following are the various modes of heating liquor now generally used.

Figs. 14 and 15 represent the old form of copper most usually erected in breweries; the former being an elevated section, and the latter a ground plan, of the fire and flue. In Fig. 14, A is the boiler or copper, hermetically sealed at the top, and convex at the bottom. Upon the top of this boiler is mounted a pan, B, containing water, which is heated by the steam arising from the boiling of the wort. A wide tube, C, rises from the uppermost part of the boiler, by which the steam generated during the ebullition of the liquor ascends, and is forced out by four tubes, two of which are seen at D D, into the liquor in the pan, B; the excess of vapour being carried off by the pipe, L, into the chimney, M. An iron shaft, E, passes down through a stuffing-box in the pipe, C, to the bottom of the vessel; at the lower end it is furnished with cross arms, from which chains are suspended, so as to sweep round the vessel. This mechanism is called "the rouser," and its object is to prevent the sediment which separates during the boiling from adhering to the bottom of the copper and getting charred. It is worked by a cogged wheel on the axis of the winch, H, gearing into the wheel, G. In order to remove the weight of the shaft off the wheel, it is partly supported at the bottom by a collar of metal borne by three stays, F F. It may be lifted by a chain, I, attached to its upper end, and, passing over the pulleys, is wound round the roller, K.

Fig. 15. Fig. 14.



This vessel, when unusually large, is heated by two fires, separated by a wall, N—Fig. 15; O O are the grates on which the fire rests, and these are supplied by short slanting iron hoppers—seen in Fig. 14—which are kept constantly full of coals. Above these hoppers is formed a narrow aperture, for the admission of air in such proportion as is sufficient to insure the complete combustion of the smoke. A bridge, R, at the back of each fire directs the flame upwards, so as to act upon the bottom of the copper, after which the heated vapours are conducted in semicircular flues, S S, round its sides, and finally enter the chimney, M, on the lower part of which a sliding damper plate, T, is placed for tempering the draught. When cold air is admitted at this orifice, the combustion of the fuel is immediately checked. Besides this, there is another slide plate at the entrance of the slanting flue into the chimney, for regulating the play of the flame under and round the boiler. If the plate, T, be opened, and the other one shut, the power of the fire is suspended. The arch of brickwork, U, over the fire, is intended to protect the front edge of the copper from the direct action of the flame. V V are the pillars on which the chimney is supported, and W is the opening through which the cinders and the ashes are drawn away.

Sometimes, instead of the steam having free exit through the pipes, D D, a weighted metallic valve, opening outward, is so arranged that no steam can escape until the liquor has reached some degrees beyond 212° Fahr., when its pressure becomes too powerful to be restrained by the weight of the valve. It then escapes, and the few degrees of extra heat which had combined with the liquid during the formation of this pressure-steam, is carried off in that which passes away, and the heat of the remainder immediately falls to 212° Fahr., when the valve closes the orifice tightly, till there is a further quantity formed which forces it open as before. In this manner the boiling is continued during the allotted time; but, instead of permitting the escape of the steam, it is conducted into water, as in the preceding figure, as well for heating the liquor as for retaining any part of the aroma which may be carried away by the vapour This water is employed in subsequent mashings. Coppers of this form are now rarely made. A copper heated by a fire beneath it is still sometimes used. It frequently has a dome with an escape pipe in the centre, to prevent the steam from spreading about the brewery.

The capacity of the hot liquor copper should be about three barrels per quarter.

Another mode of heating liquor frequently adopted is by means of a wooden tub with a copper steam coil in it.

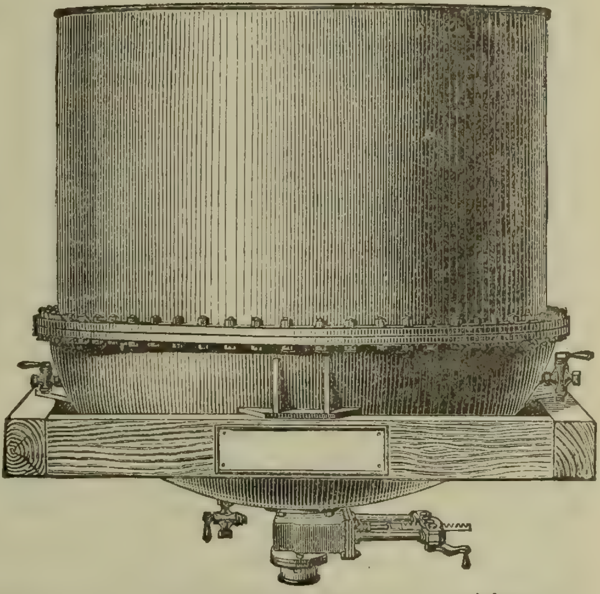
Occasionally steam is blown direct into the liquor, but this plan is not recommended, as it sometimes affects the quality of the liquor, and also makes a great deal of noise by the rapid condensation of the steam on coming in contact with the cold water.

Within the last few years a light copper vessel has been used instead of the wooden tub. Its first cost is greater, but it is cheapest in the end, owing to its superior durability, as the wooden tub will only last a few years. This copper has a steam coil like the wooden tub. There is no loss of heat by having a continuous worm for the steam, if the exit be so regulated that nothing but condensed water escapes, since this may be utilized by running it into a scalding copper for washing casks, &c.

The wort is boiled by several different means, and it is still an open question as to whether it is better to effect it by direct fire or by steam. Brewers differ considerably on this point, but the latter method is daily getting more into favour. Where fire is used a copper is employed, generally open at the top.

In boiling the wort by steam, a wooden tub and coil, or a copper vessel and coil, similar to those described for the hot liquor, may be used; but there is an objection to both, owing to the difficulty of removing the spent hops from between the tubes of the steam coil. This to some extent has been obviated by putting in a false bottom of iron, gun metal, or copper, similar to that already described for the mash-tun, so as to keep the hops from the steam coil, but the boiling is then not so satisfactory as with the fire copper.

Fig. 16.



The hops are run out through the discharge pipe with the wort, and then thrown up again from the hop back for the second wort. If the wooden tub or copper vessel be provided with a false bottom, the hops remain in, ready for the second boiling.

Undoubtedly the best method of boiling by steam is by means of the steam jacketed copper (Fig. 16). This consists of a hemispherical pan of copper, made entirely in one piece, with a cast or wrought iron jacket outside it, a space of from 2 to 3 inches being left between the two, the steam space being made tight by a flanged joint at the brims of the copper and iron pans. Above the pans, copper is continued to the required height for the capacity, this portion of the copper being comparatively thin, having to bear no pressure; but the copper pan and iron jacket must be of sufficient substance to withstand a steam pressure of usually about 30 lbs. on the square inch. The jacket into which the steam is admitted is provided with a cock for the escape of the condensed water, and also with a cock in its upper part for the escape of the heated air on commencing operations. Unless this is carefully attended to an explosion is exceedingly likely to take place, from the great expansive force exerted by air suddenly heated.

The wort is discharged through the centre of the bottom, the pipe passing through the steam space between the copper and the jacket. Inside the copper, over the discharge outlet, is placed, when desired, a large copper perforated strainer, to keep the hops back for the second boiling. When the hops are retained in the wort-boiling vessel a hop back is not required.

The capacity of the wort copper should be about three barrels per quarter, which leaves sufficient space for boiling. Its position, where the wort is not pumped, should be such that it is commanded by the under-back into which the wort runs; but where the wort is pumped, it is generally placed sufficiently high in the brewery to command the hop back, coolers, &c.

Large wort coppers are generally fitted with a "rouser," for the purpose of keeping the wort and hops agitated, and to prevent the hops from settling on the bottom of the copper and burning. The rouser is made of iron; it has a vertical shaft placed in the centre of the copper, which is driven by steam power. On the bottom of the vertical shaft is a horizontal one, reaching from side to side of the copper, on which are hung iron chains in festoons, the chains dragging on the bottom of the copper. (See Fig. 14.)

When the boiling is completed, the discharge cock of the copper is opened, and the whole contents run into the hop back. The hop back is generally of a rectangular form, from 3 to 5 feet deep, made of wood, iron, or copper, and fitted with a false bottom, similar to that of the mash-tun. Many brewers who do not object to the iron false bottom in the mash-tun, object to it in the hop back, as they consider that iron has a more detrimental effect upon the wort after it has been boiled than before.

When the wort has remained in the hop back a sufficient time to settle, it is drawn off into the cooler, leaving the hops behind; and the hops, when thoroughly strained, are carried off into the hop copper, ready for the second boiling. This is done by hand in small breweries, but in large ones it is usual to employ an elevator very similar in construction to that used for elevating grist or malt. When the hops come out of the wort copper with the second boiling, and have been strained in the hop back as they were from the first wort, they are counted as refuse, and are frequently burned in the copper furnace. In many cases the spent hops are pressed, in order to extract from them the beer that has not strained off in the hop back, an ordinary screw press being used; but in some instances hydraulic presses, specially constructed, have been used with advantage.

Opinions differ as to the advantage of pressing hops, as some brewers contend that the beer so obtained is inferior in quality, having in it a coarse bitter of the hops which is not liked, especially in beers of the finest quality.

The criterion by which practical brewers judge of the completion of the work is the "breaking," or the formation of numerous flocks of coagulated matter.

Ordinary ales, when the grist is exhausted in two or three mashings, are ordinarily boiled thus—

First wort,..................	1 hour.
Second "	2 hours.

When there are three worts the boiling is, for the

First wort,..................	1 hour.
Second "	1½ hour.
Third "	2 hours.

In these cases the first extract is boiled forty minutes before the hops are added, and fifteen minutes after; the gyle is then racked off, and the second worts are pumped into the copper and treated as specified above.

When the ale is to be stored the practice is to add the hops and continue the ebullition till the coagulated matter agglutinates and falls to the bottom, after which the whole contents of the boiler are discharged to the store cask, which, when full, is tightly bunged, and then permitted to remain till the fermentation and settling are both finished. Considerable time is required in this instance, often extending to twelve, eighteen, and even twenty-four months. Instead of putting the hops into the boiler with the wort, some persons pick or rub them between the hands, and when they are completely loosened, strew them on the bottom of the store cask, and run in the hot wort upon them after three-quarters of an hour's boil; when the cask is full it is bunged, as in the preceding instance, and, if considered necessary, a safety-valve is attached. The fermentation and cleansing take place as before. Where the object is to procure a highly-flavoured aromatic ale, this practice is no doubt successful, especially when the hops are used in larger quantities than in ordinary cases; but in commercial establishments this plan is now never adopted, though at one time it was much followed. Another custom is to macerate about a fourth of the hops with the worts, and boil—the remainder being reserved in the tun to be digested with the goods during the time allotted for the slow progressive fermentation, &c.

The trading brewers, in many cases, vary their operations, apparently with no great advantage; but the following seems to be their usual routine:—Whilst the wort is being pumped into the copper the hops are weighed out, according to the allowance per quarter, picked, and thrown on the surface of the liquor, when the boiling is performed in the open pan, but macerated with it when the closed copper is used. The layer of hops excludes contact with the air to some extent till the wort rises to ebullition, and thus any injury which might arise by spontaneous decomposition, till the temperature of the liquor reaches to 212° Fahr. (100° C.), is avoided. The steam is allowed to permeate the hops to open their pores, for the abstraction of their bitter and other constituents, for some time before they are beaten into the wort; and the boiling is continued till the formation of the flocks, or for a specified time, say one, two, or in case of stock ales which are exported, for three hours. In addition to the vegetable albumen which separates from the worts by mere boiling, the tannin of the hop unites with a further quantity and precipitates it, leaving the liquor comparatively pure, and impregnated with the preservative bitter of the hop flower.

The quantity of hops added to the worts is dependent upon the quality of the product and the strength of the worts, and also upon the length of time they are to be retained, or the climate they have to endure. The quality of the flowers has also an influence upon the proportion required to communicate the requisite properties to the liquor. For this reason the ales prepared for the export trade, such as East India pale ales, &c., are always more richly hopped than those to be used at home.

The allowance of hops per quarter of malt will be found in the annexed table by Levesque; it extends from one-eighth of a pound to 14 lbs. per quarter. Some of the fine ales, made to keep good in hot climates, have a quantity of hops added to them much larger than that which is here mentioned, amounting indeed sometimes to 18 or 22 lbs. per quarter of malt, whereas the proportion allotted to common ales is not more than from 6 to 8 lbs., and very rarely 10 lbs. For inferior ales 4 lbs. of hops per quarter of malt is sometimes thought to be sufficient.

If the produce of the malt be obtained in two or more mashings, and these are boiled separately, the proportion of hops which each wort will require is found as follows:—Suppose the quantity taken was 80 qrs. of malt, and that the gravity per quarter is 85 lbs., the whole being extracted in two mashes, the first of which tests 65 lbs., and the other, together with the washings, 20 lbs. per quarter. Further, if the proportion of hops to the quarter of 70 lbs. gravity be 12 lbs., by referring to the gravity, 85 lbs. in the table, the number 14·571 will be found on the horizontal line under the head of 12 lbs. per quarter. Then 85 × 14·571 = 1238·5 lbs. of hops, and 80 × 85 = 6800 lbs., the total extract; and 6800 = 1238·5 = 0·1821 lbs. of hops for each pound gravity in each of the worts; and hence 65 × 80 × 0·182 = 946·9 lbs for the first wort, 20 × 80 × 0·182 = 291·6 lbs. for the second wort.

In a similar way, the proportion of the flowers which ought to be added to the several liquors is found, at whatever number of pounds per quarter, as specified in the table, is adopted.

Sometimes the whole of the hops is added to the first wort; but the time of boiling is then shortened, so as to leave a sufficient amount of the bitter principle for the next liquor. The practice most frequently followed is to add the proper quantity to each wort and discharge the whole, when the usual time of boiling is expired, into the hop back. The ebullition in this case is continued for one half to three quarters of an hour longer in the second than in the first wort, to remove the excess of impurities which the after mashings generally carry along with them, and to exhaust the hops as well as to concentrate the gyle, and procure a better quality of ale than they would afford in their diluted state.

The brewer, however, applies here only an imperfect remedy for the self-inflicted evil of drawing off repeated mashings in a very diluted state, for by such a course of ebullition the sugar is partly decomposed, as already explained, the wort deepens in colour, and the expenditure in fuel becomes a dead loss. After the boiling, the gyle and hops are drawn off to the hop back, and the liquor is made to percolate through the hops used in the foregoing operation. Any strong wort which might be retained in the exhausted hops is carried off in the second gyle, and what is retained of the second is washed off with hot water, and the washings preserved for a return wort; or in case light ales are to be made, added to the product in the cooler; or the residuary fibrous matter of the hops is removed to the press, and the liquor squeezed out in this way added to the second gyle.

A larger quantity of hops is always used in hot weather then when the air is cold or mild, in order to prevent the decomposition of the ale, which, without this counteracting agent, the elevated temperature would occasion.

The following are Levesque's tables. The first shows the increase of hops required for every degree from 50° to 75° Fahr. (10° to 23°·8 C.), and from 4 to 9 lbs. per quarter:—

Temperature of the air at the time of brewing.		Four pounds per quarter.	Five pounds per quarter.	Six pounds per quarter.	Seven pounds per quarter.	Eight pounds per quarter.	Nine pounds per quarter.
Fahr.	C.						
50°	10°	4·00	5·00	6·00	7·00	8·00	9·00
51	10·5	4·08	5·10	6·12	7·14	8·16	9·18
52	11·1	4·16	5·20	6·24	7·28	8·32	9·36
53	11·6	4·24	5·30	6·36	7·42	8·48	9·54
54	12·2	4·32	5·40	6·48	7·56	8·64	9·72
55	12·7	4·40	5·50	6·60	7·70	8·80	9·90
56	13·3	4·48	5·60	6·72	7·84	8·96	10·08
57	13·8	4·56	5·70	6·84	7·98	9·12	10·26
58	14·4	4·64	5·80	6·96	8·12	9·28	10·44
59	15·0	4·72	5·90	7·08	8·26	9·44	10·52
60	15·5	4·80	6·00	7·20	8·40	9·60	10·70
61	16·1	4·88	6·10	7·32	8·54	9·76	10·88
62	16·6	4·96	6·20	7·44	8·68	9·92	11·06
63	17·2	5·04	6·30	7·56	8·82	10·08	11·24
64	17·7	5·12	6·40	7·68	8·96	10·24	11·42
65	18·3	5·20	6·50	7·80	9·10	10·40	11·60
66	18·8	5·28	6·60	7·92	9·24	10·56	11·88
67	19·4	5·36	6·70	8·04	9·38	10·72	12·06
68	20·0	5·44	6·80	8·16	9·52	10·88	12·24
69	20·5	5·52	6·90	8·28	9·66	11·04	12·42
70	21·1	5·60	7·00	8·40	9·80	11·20	12·60
71	21·6	5·68	7·10	8·52	9·94	11·36	12·78
72	22·2	5·76	7·20	8·64	10·08	11·52	12·96
73	22·7	5·84	7·30	8·76	10·22	11·68	13·14
74	23·3	5·92	7·40	8·88	10·36	11·84	13·32
75	23·8	6·00	7·50	9·00	10·50	12·00	13·50

TABLE showing the quantity of hops per quarter of malt of any gravity from 70 to 105 pounds, at the ratio of ⅛ to 14 pounds per quarter.

Gravity.	⅛	¼	½	¾	1	1¼	1½	1¾	2	2¼	2½	2¾
70	0·1250	0·2500	0·5000	0·7500	1·0000	1·2500	1·5000	1·7500	2·0000	2·2500	2·5000	2·7500
71	0·1267	0·2535	0·5070	0·7607	1·0142	1·2678	1·5214	1·7750	2·0285	2·2821	2·5864	2·7892
72	0·1284	0·2570	0·5140	0·7714	1·0284	1·2856	1·5428	1·8000	2·0570	2·3142	2·6228	2·8284
73	0·1301	0·2605	0·5210	0·7821	1·0426	1·3034	1·5642	1·8250	2·0855	2·3463	2·6592	2·8676
74	0·1318	0·2640	0·5280	0·7928	1·0568	1·3212	1·5856	1·8500	2·1140	2·3784	2·6956	2·9068
75	0·1335	0·2675	0·5350	0·8035	1·0710	1·3390	1·6070	1·8750	2·1425	2·4105	2·7320	2·9460
76	0·1352	0·2710	0·5420	0·8142	1·0852	1·3568	1·6284	1·9000	2·1710	2·4426	2·7684	2·9852
77	0·1369	0·2745	0·5490	0·8249	1·0994	1·3746	1·6498	1·9250	2·1995	2·4747	2·8048	3·0244
78	0·1386	0·2780	0·5560	0·8356	1·1136	1·3924	1·6712	1·9500	2·2280	2·5068	2·8412	3·0636
79	0·1403	0·2815	0·5630	0·8463	1·1278	1·4102	1·6920	1·9750	2·2565	2·5389	2·8776	3·1028
80	0·1420	0·2850	0·5700	0·8570	1·1420	1·4280	1·7140	2·0000	2·2850	2·5710	2·9140	3·1420
81	0·1437	0·2885	0·5770	0·8677	1·1562	1·4458	1·7354	2·0250	2·3135	2·6031	2·9504	3·1812
82	0·1454	0·2920	0·5840	0·8784	1·1704	1·4636	1·7568	2·0500	2·3420	2 6352	2·9868	3·2204
83	0·1471	0·2955	0·5910	0·8891	1·1846	1·4814	1·7782	2·0750	2·3705	2·6673	3·0232	3 2596
84	0·1488	0·2990	0·5980	0·8998	1·1988	1·5092	1·7996	2·1000	2·3990	2·6994	3·0596	3·2988
85	0·1505	0·3025	0·6050	0·9105	1·2130	1·5260	1·8210	2·1250	2·4275	2·7315	3·0960	3·3380
86	0·1522	0·3060	0·6120	0·9212	1·2272	1·5438	1·8424	2·1500	2·4560	2·7636	3·1324	3·3772
87	0·1539	0·3095	0·6190	0·9319	1·2414	1·5616	1·8638	2·1750	2·4845	2·7957	3·1688	3·4164
88	0·1556	0·3130	0·6260	0·9426	1·2556	1·5794	1·8852	2·2000	2·5130	2·8278	3·2052	3 4556
89	0·1573	0·3165	0·6330	0·9533	1·2698	1·5972	1·9066	2·2250	2·5415	2·8599	3·2416	3·4948
90	0·1590	0·3200	0·6400	0·9640	1·2840	1·6050	1·9280	2·2500	2·5700	2·8920	3·2780	3·5340
91	0·1607	0·3235	0·6470	0·9747	1·2982	1·6228	1·9494	2·2750	2·5985	2·9240	3·3144	3·5732
92	0·1624	0.3270	0·6540	0·9854	1·3124	1·6406	1·9708	2·3000	2·6270	2·9562	3·3508	3·6124
93	0·1641	0·3305	0·6610	0 9961	1·3266	1·6584	1·9922	2·3250	2·6555	2·9883	3·3872	3·6556
94	0·1658	0·3340	0·6680	1·0068	1·3408	1·6762	2·0136	2·3500	2·6840	3·0204	3·4236	3·6908
95	0·1675	0·3375	0·6750	1·0175	1·3550	1·6940	2·0350	2·3750	2·7125	3·0525	3·4600	3·7300
96	0·1692	0·3410	0·6820	1·0282	1·3692	1·7118	2·0564	2·4000	2·7410	3·0846	3·4964	3·7692
97	0·1709	0·3445	0·6890	1·0389	1·3834	1·7296	2·0778	2·4250	2·7695	3·1167	3·5328	3·8084
98	0·1726	0·3480	0·6960	1·0496	1·3976	1·7474	2·0992	2·4500	2·7980	3·1488	3·5692	3·8476
99	0·1743	0·3515	0·7030	1·0603	1·4118	1·7652	2·1206	2·4750	2·8265	3·1809	3·6056	3·8868
100	0·1760	0·3550	0·7100	1·0710	1·4260	1·7830	2·1423	2·5000	2·8550	3·2130	3·6420	3·9260
101	0·1777	0·3580	0·7170	1·0817	1·4402	1·8008	2·1634	2·5250	2·8835	3·2451	3·6784	3·9652
102	0·1794	0·3620	0·7240	1·0924	1·4544	1·8186	2·1848	2·5500	2·9120	3·2772	3·7148	4·0044
103	0·1811	0·3655	0·7310	1·1031	1·4686	1·8364	2·2062	2·5750	2·9405	3·3093	3·7512	4·0436
104	0·1828	0·3698	0·7380	1·1008	1·4828	1·8542	2·2276	2·6000	2·9690	3·3414	3·7876	4·0828
105	0·1845	0·3725	0·7450	1·1245	1·4970	1·8720	2·2490	2·6250	2·9975	3·3735	3·8240	4·1220

TABLE continued.

Gravity.	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾
70	3·0000	3·2500	3·5000	3·7500	4·0000	4·2500	4·5000	4·7500	5·0000	5·2500	5·5000	5·7500
71	3·0428	3·2964	3·5500	3·8035	4·0571	4·3107	4·5642	4·8178	5·0714	5 3250	5·5785	5·8321
72	3·0856	3·3428	3·6000	3·8570	4·1142	4·3714	4·6284	4·8856	5·1428	5·4000	5·6570	5·9142
73	3·1284	3·3892	3·6500	3·9705	4·1713	4·4321	4·6926	4·9534	5·2142	5·4750	5·7355	5·9963
74	3 1712	3·4356	3·7000	3·9640	4·2284	4·4928	4·7568	5·0212	5·2856	5·5500	5·8140	6·0784
75	3·2140	3·4820	3·7500	4·0175	4·2855	4·5535	4·8210	5·0890	5·3570	5·6250	5·8925	6·1605
76	3·2568	3·5284	3·8000	4·0710	4·3426	4·6142	4·8852	5·1568	5·4284	5·7000	5·9710	6·2426
77	3·2996	3·5748	3·8500	4·1245	4·3994	4·6749	4·9494	5·2246	5·4998	5·7750	6·0495	6·3247
78	3·3424	3·6212	3·9000	4·1780	4·4568	4·7356	5·0136	5·2924	5·5712	5·8500	6·1280	6·4068
79	3·3852	3·6676	3·9500	4·2315	4·5139	4·7963	5·0778	5·3602	5·6426	5·9250	6·2065	6·4889
80	3·4280	3·7140	4·0000	4·2850	4·5710	4·8570	5·1420	5·4280	5·7140	6·0000	6·2850	6·5710
81	3·4708	3·7604	4·0500	4·3385	4·6281	4·9177	5·2062	5·4958	5·7854	6·0750	6·3635	6·6531
82	3·5136	3·8068	4·1000	4·3920	4·6852	4·9784	5·2704	5·5636	5·8568	6·1500	6·4420	6·7352
83	3·5564	3·8532	4·1500	4·4455	4·7423	5·0391	5·3346	5·6314	5·9282	6·2250	6·5205	6·8173
84	3·5992	3·8996	4·2000	4·4990	4·7994	5·0998	5·3998	5·6992	5·9996	6·3000	6·5990	6·8994
85	3·6420	3·9460	4·2500	4·5525	4·8565	5·1605	5·4640	5·7670	6·0710	6·3750	6·6775	6·9815
86	3·6848	3·9924	4·3000	4·6060	4·9136	5·2212	5·5272	5·8348	6·1424	6·4500	6·7560	7·0636
87	3·7276	4·0388	4·3500	4·6595	4·9707	5·2819	5·5914	5·9026	6·2138	6·5250	6·8345	7·1457
88	3·7704	4·0852	4·4000	4·7130	5·0278	5·3426	5·6556	5·9704	6·2852	6·6000	6·9130	7·2278
89	3·8132	4·1316	4·4500	4·7665	5·0849	5·4033	5·7198	6·0382	6·3566	6·6750	6·9915	7·3099
90	3·8560	4·1780	4·5000	4·8200	5·1420	5·4640	5·7840	6·1060	6·4280	6·7500	7·0700	7·3920
91	3·8988	4·2244	4·5500	4·8735	5·1991	5·5247	5·8482	6·1738	6·4994	6·8250	7·1485	7·4741
92	3·9416	4·2708	4·6000	4·9270	5·2562	5·5854	5·9124	6·2416	6·5708	6·9000	7·2270	7·5562
93	3·9844	4·3172	4·6500	4·9805	5·3133	5·6461	5·9766	6·3094	6·6422	6·9750	7·3055	7·6383
94	4·0272	4·3636	4·7000	5·0340	5·3704	5·7068	6·0408	6·3772	6·7136	7·0500	7·3840	7·7204
95	4·0700	4·4100	4·7500	5·0875	5·4275	5·7675	6·1050	6·4450	6·7850	7·1250	7·4625	7·8025
96	4·1128	4·4564	4·8000	5·1410	5·4846	5·8282	6·1692	6·5128	6·8564	7·2000	7·5410	7·8846
97	4·1556	4·5028	4·8500	5·1945	5·5417	5·8889	6·2334	6·5806	6·9278	7·2750	7·6195	7·9667
98	4·1984	4·5492	4·9000	5·2480	5·5988	5·9496	6·2976	6·6484	6·9992	7·3500	7·6980	8·0488
99	4·2412	4·5956	4·9500	5·3015	5·6559	6·0103	6·3618	6·7162	7·0706	7·4250	7·7765	8·1309
100	4·2840	4·6420	5·0000	5·3550	5·7130	6·0710	6·4260	6·7840	7·1420	7·5000	7·8550	8·2130
101	4·3268	4 6884	5·0500	5·4085	5·7701	6·1317	6·4902	6·8518	7·2134	7·5750	7·9335	8·2951
102	4·3696	4·7348	5·1000	5·4620	5·8272	6·1924	6·5544	6·9196	7·2848	7·6500	8·0120	8·3772
103	4·4124	4·7812	5·1500	5·5155	5·8843	6·2531	6·6186	6·9874	7·3562	7·7250	8·0905	8·4593
104	4·4552	4·8276	5·2000	5·5690	5·9414	6·3138	6·6828	7·0552	7·4276	7·8000	8·1690	8·5414
105	4·4980	4·8740	5·2500	5·6225	5·9985	6·3745	6·7470	7·1230	7·4990	7·8750	8·2475	8·6235

Table showing the quantity of hops per quarter of malt of any gravity from 70 to 105 pounds, at the ratio of ⅛ to 14 pounds per quarter.—Continued.

Gravity.	6	6¼	6½	6¾	7	7¼	7½	7¾	8	8¼	8½
70	6·0000	6·2500	6·5000	6·7500	7·0000	7·2500	7·5000	7·7500	8·0000	8·2500	8·5000
71	6·0857	6·3392	6·5928	6·8464	7·1000	7·3535	7·6071	7·8607	8·1142	8·3678	8·6214
72	6·1714	6·4284	6·6856	6·9428	7·2000	7·4570	7·7142	7·9714	8·2284	8·4856	8·7428
73	6·2571	6·5176	6·7784	7·0392	7·3000	7·5605	7·8213	8·0821	8·3426	8·6034	8·8642
74	6·3428	6·6068	6·8712	7·1356	7·4000	7·6640	7·9284	8·1928	8·4568	8·7212	8·9850
75	6·4285	6·6960	6·9640	7·2320	7·5000	7·7675	8·0355	8·3035	8·5710	8·8390	9·1070
76	6·5142	6·7852	7·0568	7·3284	7·6000	7·8710	8·1426	8·4142	8·6852	8·9568	9·2284
77	6·5999	6·8744	7·1496	7·4240	7·7000	7·9745	8·2497	8·5249	8·7994	9·0746	9·3498
78	6·6856	6·9636	7·2424	7·5212	7·8000	8·0780	8·3568	8·6356	8·9136	9·1924	9·4712
79	6·7713	7·0528	7·3352	7·6176	7·9000	8·1815	8·4639	8·7463	9·0278	9·3102	9·5927
80	6·8570	7·1420	7·4280	7·7140	8·0000	8·2850	8·5710	8·8570	9·1420	9·4280	9·7140
81	6·9427	7·2312	7·5208	7·8104	8·1000	8·3885	8·6781	8·9677	9·2562	9·5458	9·8354
82	7·0284	7·3204	7·6136	7·9068	8·2000	8·4920	8·7852	9·0784	9·3704	9·6636	9·9568
83	7·1141	7·4096	7·7064	8·0032	8·3000	8·5955	8·8923	9·1891	9·4846	9·7814	10·0782
84	7·1998	7·4988	7·7992	8·0996	8·4000	8·6996	8·9994	9·2998	9·5998	9·8992	10·1996
85	7·2855	7·5880	7·8920	8·1960	8·5000	8·8025	9·1065	9·4105	9·7130	10·0170	10·3210
86	7·3712	7·6772	7·9848	8·2924	8·6000	8·9060	9·2136	9·5212	9·8272	10·1348	10·4424
87	7·4569	7·7664	8·0776	8·3888	8·7000	9·0005	9·3207	9.6319	9·9414	10·2526	10·5638
88	7·5426	7·8556	8·1704	8·4852	8·8000	9·1130	9·4278	9·7426	10·0516	10·3704	10·6852
89	7·6283	7·9448	8·2632	8·5816	8·9000	9·2165	9·5349	9·8533	10·1698	10·4882	10·8006
90	7·7140	8·0340	8·3560	8·6780	9·0000	9·3200	9·6420	9·9640	10·2840	10·6060	10·9280
91	7·7997	8·1232	8·4488	8·7744	9·1000	9·4235	9·7491	10·0747	10·3982	10·7238	11·0494
92	7·8854	8·2124	8·5416	8·8708	9·2000	9·5270	9·8562	10·1854	10·5124	10·8416	11·1708
93	7·9771	8·3016	8·6344	8·9672	9·3000	9·6305	9·9633	10·2961	10·6266	10·9514	11·2922
94	8·0568	8·3908	8·7272	9·0636	9·4000	9·7340	10·0704	10·4068	10·7408	11·0772	11·4136
95	8·1425	8·4800	8·8200	9·1600	9·5000	9·8375	10·1775	10·5175	10·8550	11·2950	11·5350
96	8·2282	8·5692	8·9128	9·2564	9·6000	9·9410	10·2846	10·6282	10·9692	11·3128	11·6564
97	8·3139	8·6584	9·0056	9·3528	9·7000	10·0445	10·3917	10·7389	11·0834	11·4306	11·7778
98	8·3996	8·7476	9·0984	9·4492	9·8000	10·1480	10·4988	10·8496	11·1976	11·5484	11·8992
99	8·4853	8·8368	9·1912	9·5456	9·9000	10·2515	10·6059	10·9603	11·3118	11·6662	12·0206
100	8·5710	8·9260	9·2840	9·6420	10·0000	10·3550	10·7130	11·0710	11·4260	11·7840	12·1420
101	8·6567	9·0152	9·3768	9·7384	10·1000	10·4585	10·8201	11·1817	11·5402	11·9018	12·2634
102	8·7424	9·1044	9·4696	9·8348	10·2000	10·5620	10·9272	11·2924	11·6544	12·0196	12·3848
103	8·8281	9·1936	9·5624	9·9312	10·3000	10·6655	11·0343	11·4031	11·7686	12·1374	12·5062
104	8·9138	9·2828	9·6552	10·0276	10·4000	10·7690	11·1414	11·5138	11·8828	12·2552	12·6267
105	8·9995	9·3720	9·7480	10·1240	10·5000	10·8725	11·2485	11·6245	11·9970	12·3730	12·7490

Table continued.

Gravity.	8¾	9	9¼	9½	9¾	10	10¼	10½	10¾	11	11¼
70	8·7500	9·0000	9·2500	9·5000	9·7500	10·0000	10·2500	10·5000	10·7500	11·0000	11·2500
71	8·8750	9·1285	9·3821	9·6357	9·8892	10·1428	10·3964	10·6500	10·9035	11·1571	11·4107
72	9·0000	9·2570	9·5142	9·7714	10·0284	10·2856	10·5428	10·8000	11·0570	11·3142	11·5714
73	9·1250	9·3855	9·6463	9·9071	10·1676	10·4284	10·6892	10·9500	11·2105	11·4713	11·7321
74	9·2500	9·1140	9·7784	10·0428	10·3068	10·5712	10·8356	11·1000	11·3640	11·6284	11·8928
75	9·3750	9·6465	9·9105	10·1785	10·4460	10·7140	10·9820	11·2500	11·5175	11·7855	12·0535
76	9·5000	9·7710	10·0426	10·3142	10·5852	10·8568	11·1284	11·4000	11·6710	11·9426	12·2142
77	9·6250	9·8995	10·1747	10·4499	10·7244	10·9996	11·2748	11·5500	11·8245	12·0997	12·3749
78	9·7500	10·0280	10·2068	10·5856	10·8636	11·1424	11·4212	11·7000	11·9780	12·2568	12·5356
79	9·8750	10·1565	10·4389	10·7213	11·0028	11·2852	11·5676	11·8500	12·1315	12·4139	12·6963
80	10·0000	10·2850	10·5710	10·8570	11·1420	11·4280	11·7140	12·0000	12·2850	12·5710	12·8570
81	10·1250	10·4135	10·7031	10·9927	11·2812	11·5708	11·8604	12·1500	12·4385	12·7281	13·0177
82	10·2500	10·5420	10·8352	11·1284	11·4204	11·7136	12·0068	12·3000	12·5920	12·8852	13·1784
83	10·3750	10·6705	10·9673	11·2641	11·5296	11·8564	12·1532	12·4500	12·7455	13·0423	13·3391
84	10·5000	10·7990	11·0994	11·3998	11·6988	11·9992	12·2996	12·6000	12·8990	13·1994	13·4998
85	10·6250	10·9275	11·2315	11·5355	11·8380	12·1420	12·4460	12·7500	13·0525	13·3565	13·6605
86	10·7500	11·0560	11·3636	11·6712	11·9772	12·2848	12·5924	12·9000	13·2660	13·5136	13·8212
87	10·8750	11·1845	11·4957	11·8069	12·1164	12·4276	12·7388	13·0500	13·3595	13·6707	13·9819
88	11·0000	11·3130	11·6278	11·9426	12·2556	12·5704	12·8852	13·2000	13·5130	13·8278	14·1426
89	11·1250	11·4415	11·7599	12·0783	12·3948	12·7132	13·0316	13·3500	13·6665	13·9849	14·3033
90	11·2500	11·5700	11·8920	12·2140	12·5340	12·8560	13·1780	13·5000	13·8200	14·1420	14·4640
91	11·3750	11·6985	12·0241	12·3497	12·6732	12·9988	13·3244	13·6500	13·9735	14·2991	14·6247
92	11·5000	11·8270	12·1562	12·4854	12·8124	13·1416	13·4708	13·8000	14·1270	14·4562	14·7854
93	11·6250	11·9555	12·2883	12·6211	12·9516	13·2844	13·6172	13·9500	14·2805	14·6133	14·9461
94	11·7500	12·0840	12·4204	12·7568	13·0908	13·4272	13·7636	14·1000	14·4340	14·7704	15·1068
95	11·8750	12·2125	12·5525	12·8925	13·2300	13·5700	13·9100	14·2500	14·5875	14·9275	15·2675
96	12·0000	12·4410	12·6846	13·0282	13·3692	13·7128	14·0564	14·4000	14·7410	15·0846	15·4282
97	12·1250	12·5695	12·8167	13·1639	13·5084	13·8556	14·2028	14·5500	14·8945	15·2417	15·5899
98	12·2500	12·6980	12·9488	13·2996	13·6476	13·9984	14·3492	14·7000	15·0480	15·3988	15·7496
99	12·3750	12·8265	13·0809	13·4353	13·7868	14·1412	14·4496	14·8500	15·2015	15·5559	15·9103
100	12·5000	12·9550	13·2130	13·5710	13·9260	14·2840	14·6420	15·0000	15·3550	15·7130	16·0710
101	12·6250	13·0835	13·3451	13·7067	14·0652	14·4268	14·7884	15·1500	15·5085	15·8701	16·2317
102	12·7500	13·2120	13·4772	13·8424	14·2044	14·5696	14·9348	15·3000	15·6620	16·0272	16·3924
103	12·8750	13·3405	13·5093	13·9781	14·3436	14·7124	15·0812	15·4500	15·8155	16·1843	16·5531
104	13·0000	13·4680	13·7414	14·1138	14·4828	14·8552	15·2276	15·6000	15·9690	16·3414	16·7138
105	13·1250	13·5965	13·8735	14·2495	14·6220	14·9980	15·3740	15·7500	16·1225	16·4985	16·8745

TABLE showing the quantity of hops per quarter of malt of any gravity from 70 to 105 pounds, at the ratio of ⅛ to 14 lbs. per quarter.—Concluded.

Gravity.	11½	11¾	12	12¼	12½	12¾	13	13¼	13½	13¾	14
70	11·5000	11·7500	12·0000	12·2500	12·5000	12·7500	13·0000	13·2500	13·5000	13·7500	14·0000
71	11·6642	11·9178	12·1714	12·4250	12·6785	12·9321	13·1857	13·4392	13·6928	13·9464	14·2000
72	11·8284	12·0856	12·3428	12·6000	12·8570	13·1142	13·3714	13·6284	13·8865	14·1428	14·4000
73	11·9926	12·2534	12·5412	12·7750	13·0320	13·2963	13·5571	13·8176	14·0784	14·3392	14·6000
74	12·1568	12·4212	12·6856	12·9500	13·2105	12·4784	13.7428	14·0068	14·2712	14·5356	14·8000
75	12·3210	12·5890	12·8570	13·1250	13·3890	13·6605	13·9285	14·1960	14·4640	14·7320	15·0000
76	12·4852	12·7568	13·0284	13·3000	13·5675	13·8426	14·1142	14·3852	14·6568	14·9284	15·2000
77	12·6494	12·9246	13·1998	13·4750	13·7460	14·0247	14·2999	14·5744	14·8496	15·1248	15·4000
78	12·8136	13·0924	13·3712	13·6500	13·9245	14·2068	14·4856	14·7636	15·0424	15·3212	15·6000
79	12·9778	13·2602	13·5426	13·8250	14·1030	14·3889	14·6713	14·9528	15·2352	15·5176	15·8000
80	13·1420	13·4280	13·7140	14·0000	14·2815	14·5710	14·8570	15·1410	15·4280	15·7140	16·0000
81	13·3062	13·5958	13·8885	14·1750	14·4600	14·7531	15·0427	15·3302	15·6208	15·9404	16·2000
82	13·4704	13·7636	14·0568	14·3500	14·6385	14·9352	15·2281	15·5194	15·8136	16·1068	16·4000
83	13·6346	13·9314	14·2282	14·5250	14·8170	15·1173	15·4141	15·7086	16·0064	16·3032	16·6000
84	13·7988	14·0992	14·3996	14·7000	14·9955	15·2994	15·5998	15·8978	16·1992	16·4996	16·8000
85	13·9630	14·2670	14·5710	14·8750	15·1740	15·4815	15·7855	16·0870	16·3920	16·6960	17·0000
86	14·1272	14·4348	14.7424	15·0500	15·3525	15·6636	15·9712	16·2762	16·5848	16·8924	17·2000
87	14·2914	14·6026	14·9138	15·2250	15·5310	15·8457	16·1569	16·4654	16·7776	17·0888	17·4000
88	14·4556	14·7740	15·0852	15·4000	15·7095	16·0278	16·3426	16·6546	16·9704	17·2852	17·6000
89	14·6198	14·9382	15·2566	15·5750	15·8880	16·2099	16·5283	16·8438	17·1632	17·4816	17·8000
90	14·7840	15·1060	15·4280	15·7500	16·0665	16·3920	16·7146	17·0320	17·3560	17·6780	18·0000
91	14·9482	15·2738	15·5994	15·9250	16·2450	16·5741	16·8997	17·2212	17·5488	17·8744	18·2000
92	15·1124	15·4416	15·7708	16·1000	16·4235	16·7562	17·0854	17·4104	17·7416	18·0708	18·4000
93	15·2706	15·6694	15·9422	16·2750	16·6020	16·9383	17·2711	17·6096	17·9344	18·2672	18·6000
94	15·4408	15·7772	16·1136	16·4500	16·7805	17·1204	17·4568	17·7988	18·1272	18·4636	18·8000
95	15·6050	15·9450	16·2850	16·6250	16·9590	17·3025	17·6425	17·9880	18·3200	18·6600	19·0000
96	15·7692	16·1128	16·4564	16·8000	17·1375	17·4846	17·8282	18·1772	18·5128	18·8564	19·2000
97	15·9334	16·2806	16·6278	16·9750	17·3160	17·6667	18·0139	18·3664	18·7056	19·0528	19·4000
98	16·0976	16·4484	16·7992	17·1500	17·4945	17·8488	18·1996	18·5556	18·8984	19·2492	19·6000
99	16·2618	16·6162	16·9706	17·3250	17·6730	18·0309	18·3853	18·7448	19·0912	19·4456	19·8000
100	16·4260	16·7840	17·1420	17·5000	17·8515	18·2130	18·5710	18·9340	19·2840	19·6420	20·0000
101	16·5902	16·9518	17·3134	17·6750	18·0300	18·3951	18·7567	19·1232	19·4768	19·8384	20·2000
102	16·7544	17·1196	17·4848	17·8500	18·2085	18·5772	18·9424	19·3124	19·6696	20·0348	20·4000
103	16·9186	17·2874	17·6562	18·0250	18·3870	18·7593	19·1281	19·5016	19·8624	20·2312	20·6000
104	17·0828	17·4552	17·8276	18·2500	18·5655	18·9414	19·3138	19·6908	20·0552	20·4276	20·8000
105	17·2470	17·6230	17·9990	18·3750	18·7440	19·1235	19·4995	19·8800	20·2480	20·6240	21·0000

During the boiling considerable quantities of water are expelled as steam, and a great difference is consequently observed between the density of the wort after boiling, and the gravity which it indicated at the time of its introduction into the copper.

The annexed table, also by LEVESQUE, shows what gravity the original wort should possess to afford a gyle of a certain strength after one hour's boiling:—

Gravity required after one hour's boiling	Gravity required in the raw wort	Gravity required after one hour's boiling.	Gravity required in the raw wort
8	6·60	27	21·60
9	7·20	28	22·40
10	8·00	29	23·20
11	8·80	30	24·00
12	9·60	31	24·80
13	10·40	32	25·60
14	11·20	33	26·40
15	12·00	34	27·20
16	12·80	35	28·00
17	13·60	36	28·80
18	14·40	37	29·60
19	15·20	38	30·40
20	16·00	39	31·20
21	16·80	40	32·00
22	17·60	41	32·80
23	18·40	42	33·60
24	19·20	43	34·40
25	20·00	44	35·20
26	20·80	45	36·00

As some brewers press the spent hops after the last mashing in order to secure all the liquor they contain, it is desirable to know how much of the worts is held by strained hops.

According to RICHARDSON, the volume of wort imbibed by the hops is as follows:—

Hops used.	Wort imbibed.	Hops used.	Wort imbibed
Pounds.	Bar.	Pounds.	Bar.
1	0·01	30	0·50
2	0·03	40	0·66
3	0·05	50	0·83
4	0·06	60	1·00
5	0·08	70	1·16
6	0·10	80	1·33
7	0·11	90	1·50
8	0·13	100	1·66
9	0·15	200	3·33
10	0·16	300	5·00
11	0·17	400	6·66
12	0·19	500	8·33
13	0·21	600	10·00
14	0·22	700	11·66
15	0·24	800	13·32
16	0·26	900	15·00
17	0·27	1000	16·66
18	0·29	2000	33·30
19	0·31	3000	50·00
20	0·33	4000	66·66

The back into which the hops and wort are discharged is usually a large square vessel of wood or iron, with a perforated false bottom and a tap appended, not unlike the construction of the mash-tun. When the contents of the copper are to be drawn off, the "rouser," or other agitating apparatus, is set in motion to raise the hops in the liquor; and when the whole is removed to the back, some time is allowed to elapse before the gyle is drawn off to the refrigerators, in order that the hops may subside, and retain any mechanical impurities which may be floating in the liquid as it filters through them.

Many brewers, especially in Scotland, instead of employing an apparatus like that above mentioned, erect a large square, with a temporary bottom or strainer, made of hair, and into this the hops and gyle are discharged. In this case the liquor is not so transparent as in the former; but it is held that the finer portions of the hop grains which are carried through with the coagulated albumen are serviceable as a preservative to the beer, chiefly on the ground that a larger quantity of albuminous and glutinous matter is deposited with the hop grains in the coolers, and that the gyle is therefore much better purified than by the practice of filtering through the hops, as in the first method.

Cooling.—After the worts are thoroughly hopped and boiled, the next thing to be done is to bring them to a proper temperature for the commencement of the fermentation, which, to insure success, must be conducted within certain limits. The liquor, in this case, must be rapidly cooled, for if permitted to remain too long in contact with the air, unless the atmosphere is very cold, acidity speedily occurs. Two methods are resorted to for cooling the worts. The first has been practised for a considerable period; but the latter, which is of recent introduction, is much more effectual, and is now most generally adopted.

The apparatus used in the first instance is known as the *cooler*, and in the second as the *refrigerator*.

In some small breweries the wort copper is placed sufficiently high for the wort to run from the hop back to the coolers, but in large breweries the wort copper is generally placed near the ground, and the coolers in the upper part of the building. In this case the wort has to be pumped up to the coolers from the hop back. The coolers must be placed in an airy situation, with louvre boards on all sides if possible, to cause a draught.

Coolers are spacious rectangular shallow vessels, for the most part constructed of Dantzic deal boards 2 inches thick at the sides, and 1¼ inch or 1½ at the bottom; these boards are connected by plain joints, to which they are secured by pins of the same wood. The depth of the cooler is about 6 inches, and it should be perfectly smooth, so that no impurities can be retained, which would be the case when the worts are drawn off, were any inequalities or rough knots in the floor; it should have a gentle incline towards that end at which the gyle is discharged into the fermenting-backs, and be placed in a position where the air has free access to it. For this reason the cooling floor is always in an elevated part of the brewery, and exposed on all sides by means of louvre boards arranged in the same manner as a Venetian sun-blind, to create a draught. To expedite the work, various mechanical contrivances are used, to increase the current of air in the apartment, whereby the heat is more readily dissipated than if allowed to diffuse by radiation. The gyle is streamed upon this floor to the depth of 2 or 2½ inches, and when the atmosphere is rather cold, as from the latter end of autumn to the middle of spring, the stratum cools in six to eight hours; but even this is too long a time for the liquor to remain exposed to the air.

Considerable loss, indeed, is often incurred by the imperfection of this method of cooling by the wooden floor, especially in warm weather, when the atmosphere is of a comparatively high temperature; for, in the first place, the liquor is not reduced in its heat so readily as to be entirely exempt from acidity; and, in the second, the wood of the vessel experiences considerable change in the alternate application of heat and cold, by which its pores are distended so much, that if allowed to remain exposed for any length of time air enters, and this coming in contact with the gyle in the next operation, it operates on its saccharine and albuminous constituents, and occasions a creaming of the surface, or an incipient fermentation, technically known as the "fox."

This evil may be partially prevented by keeping the floor covered with cold water, after the worts have been drawn off and the deposited matter cleaned away, till the next operation; but still the wood is liable to communicate acidity, unless the greatest attention be given to its being thoroughly washed very frequently with lime water.

Though generally made of wood, the coolers are occasionally made of other materials. A few years ago Messrs. Truman & Co., the well-known London brewers, erected some coolers made of sheet copper, which have turned out most satisfactorily; and no doubt the considerable expense of copper coolers is the only cause to prevent their general adoption.

When the brewer depended almost entirely upon the coolers for bringing his wort down to the required temperature, they required to be very large, and then coolers to the extent of 100 square feet area per quarter were needed; but refrigerators are now almost invariably used, and the coolers are much smaller and often 2 or more feet deep.

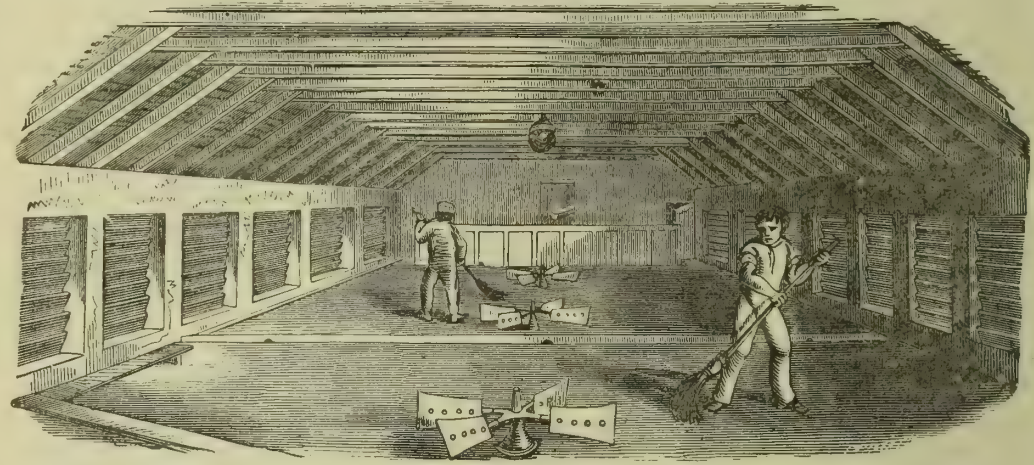
Fans are sometimes used for causing a draught for the wort when in the coolers. One form of fan is a vertical shaft fixed in the centre of the cooler, with horizontal arms on it near the surface of the wort, the whole being revolved by steam power. Fig. 17 represents a cooler with three such fans. In other cases a fan-blowing machine has been used, the blast being carried through a horizontal pipe placed right along one side of the cooler, having a slot along its whole length, through which the blast issues.

In some breweries coolers are entirely dispensed with, a sufficiently powerful refrigerator being used to reduce the wort to the necessary degree of coolness. There is no doubt that the use of refrigerators has great advantages over the old-fashioned coolers, both time and space being considerably economized by their employment.

The refrigerators occupy much less space than the plain coolers; they are sometimes constructed, like the latter, in the form of a plane, with transverse divisions or bars issuing from each side alternately, and reaching to within half a foot of the opposite side; the space between each bar is usually about a foot or a foot and a half, and in this a pipe of suitable calibre is laid, through which cold water is made to flow in an opposite direction to the current of the gyle.

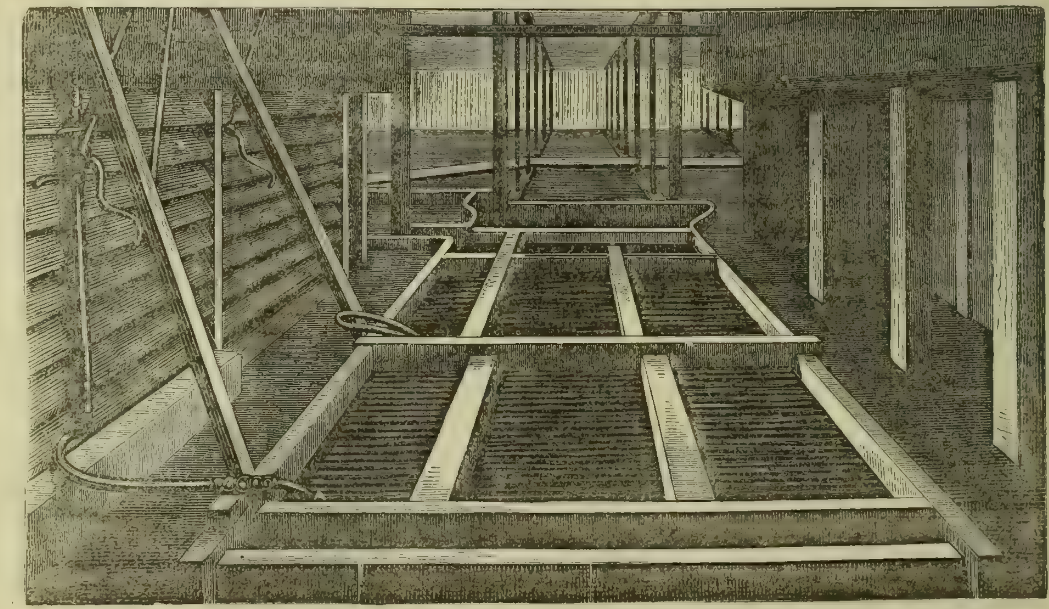
Fig. 18 represents the refrigerator in use at the brewery of Messrs. ALLSOPP & SONS; the water pipe, entering at the lower end, is seen at A, and passes off at the further end, where the hot worts are being discharged into the cooler.

Fig. 17.



During the last twenty years a great number of patents have been granted for refrigerators; but it will be sufficient to describe a few of those most generally in use. Compactness, durability, facilities for cleaning and repair, are points which must be considered in determining which is the best refrigerator, and unfortunately it is not easy to find any one refrigerator in which all these qualities are combined. There is also a great difference of opinion as to whether the wort should or should not be greatly exposed when being cooled; and it will be seen by the following descriptions that in some refrigerators the wort passages are entirely closed, and in others the wort is exposed during the whole time of refrigerating.

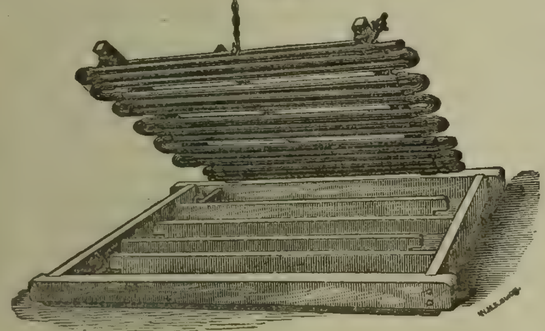
Fig. 18.



Previous to 1856 there was very little improvement in the form of refrigerators; that mostly in use (Fig. 19) consisted of a number of tinned copper pipes from 8 to 12 feet long, connected at the ends by bends and laid horizontally in a wooden back or cooler about 6 inches deep. Between every third pipe was a wooden division joined to the back at one end, but not reaching the other end of the back by about 6 inches. This division made a channel for the flow of wort, the cold liquor passing through the pipes in a contrary direction. The pipes could be raised for cleaning, as shown in the illustration. This kind of refrigerator is still frequently used in small breweries, and is found to be good and serviceable for breweries up to about 8 or 10 quarters, or where coolers are used. But this form of refrigerator is only calculated to cool wort from a temperature of 90° Fahr. (32°·2 C.). For large breweries it is unwieldy; neither will it do when coolers are dispensed with, that is to say, when the wort enters the refrigerator at a temperature of about 150° Fahr. (65°·5 C.).

In 1856 G. Riley patented a refrigerator that soon came into extensive use. It consists of a number of small block-tin pipes bent into horizontal coils lying one above the other, through which the wort runs. Between each circle is a metallic vertical division, forming a continuous passage, in which the cold liquor runs in a contrary direction to that of the wort. The objection to this refrigerator is that brewers find it difficult to clean the pipes which convey the wort.

Fig. 19.



In 1859 Baudelot's refrigerator was patented: it differs entirely from Riley's. Baudelot's refrigerator consists of a number of copper pipes placed horizontally one above the other, and connected at the ends by bends, the under side of each pipe having a strip of metal on it with a saw-toothed edge. The wort to be cooled is delivered on the top pipe through a perforated trough, and trickles down the whole series of pipes, the cold liquor passing upwards through the pipes.

Lawrence's refrigerator is similar in principle to Baudelot's, but is different in construction, having corrugated sheets of copper instead of pipes.

In 1860 H. Bridle patented a very effective refrigerator. It consists of a copper case, open on the top, in which is fixed a series of thin flat copper pipes about 5½ inches in depth and ½ inch thick, at intervals of about ¾ of an inch. Each pipe is divided through its length into two 2¾-inch pipes, through which the cold liquor passes in two columns, one over the other, in opposite directions. The pipes are connected outside the case by metal boxes. The wort enters the case at the opposite end to that at which the cold liquor enters, passes underneath one pipe, rises to its level, and then falls over the next pipe; and so on, alternately over one and underneath the next till it comes to the end of the case, where it flows out.

The refrigerators of Riley, Baudelot, Lawrence, and Bridle occupy but little space, and are suitable for cooling large quantities; Riley's and Bridle's are small in height, but Baudelot's and Lawrence's are some feet in height, which sometimes operates against their adoption, since it necessitates the wort being pumped up to them.

Many other forms of refrigerators are made, but it is not necessary to describe them, as they do not differ greatly in principle from those mentioned, and the opinions of brewers differ so much on this point that it is difficult to assign to any pre-eminence for adaptability or utility.

When the worts are cooled on the open floor, considerable quantities of deposits are formed, which in some cases are swept off into the fermenting-backs. The chief aim of the manager should be to cool the liquor as rapidly as possible, especially when the temperature reaches 130° Fahr. (54°·4 C.). The floor and pipes should be kept most scrupulously clean, otherwise the goods will either acquire a very bad taste or turn acid.

The best materials for cleansing coolers are chloride of lime and quicklime, or a mixture of the two, but not bisulphite of lime. Chloride of lime contains oxygen in a form that can very readily be given up; whilst sulphurous acid readily absorbs oxygen. The bisulphite is, therefore, a very valuable cleansing agent when acetification only is feared; but when the "fox," *i.e.*, a putrescent fermentation, has to be got rid of, it is better to use a substance like chloride of lime, which oxidizes, or burns up and destroys the germs or other impurities causing the mischief. Of course, boiling water must be copiously used to remove the detergents employed.

The wort being now cooled to the proper temperature for fermentation, generally about 58° to 60° Fahr. (14°·4 to 15°·5 C.), it runs into the fermenting tun.

Fermentation.—In the whole course of brewing, there is no part of the work which requires such indefatigable diligence as the fermentation of the wort, as upon it depends the perfect accomplishment of the business. If the foregoing stages have been performed somewhat imperfectly, provided the products have not acidified, if they are subjected to a good fermentation, a wholesome beverage is obtained; but let the mashing and the other operations be ever so studiously executed, if the fermentation is imperfect, a bad and almost worthless product results. By care and moderate experience, however, brewing may be easily so managed as to guard against the possibility of a failure.

The theory of fermentation of Liebig, Gay Lussac, Gerhardt, Mülder, and others is, that under certain conditions a nitrogenous body, having an albumenoid character, breaks down and decomposes; its equilibrium is disturbed, and in that disturbance it is able to communicate a disturbance of equilibrium to the sugar molecule that may be found near it. Hence, therefore, they consider that the process of fermentation is entirely a chemico-physical one. GAY LUSSAC held that the oxidation of albuminous matter was an essential feature of the process; and this is to some extent true, only that, as already stated (see ALCOHOL), fermentation will go on even when no air is present. At the same time, air does seem to start the fermentation process. The other and now generally adopted theory is due to SCHWANN, a German chemist and physiologist, who, about the year 1836, maintained that there was no real case of fermentation unless cells of living organisms were present, and that these were the agents of the change. Hence, therefore, arose the theory of its being a vital phenomenon.

Later on PASTEUR took up the subject and worked at it with that wonderful energy and scientific acumen for which he is so distinguished. His experiments were carried on for years, and proved fully that fermentations are the results of vital processes. He maintains that the alcoholic fermentation is not due to the decay, to the putrefaction of the cells, of which yeast is composed, but is due to the action of the living and growing organisms. It has been objected that diastase, and many animal secretions, are able to convert starch into sugar; and not only that, but when alcohol is acted upon by oxygen in the presence of platinum black, the alcohol is oxidized first to the state of aldehyde, and then to the state of acetic acid, these phenomena being held to be distinctly phenomena of fermentation. But from PASTEUR'S point of view the conversion of starch into sugar is not a case of fermentation at all, since dilute sulphuric acid can at 212° Fahr. (100° C.) effect the same change. Acetic acid is also, under certain conditions, obtained from alcohol; but no purely physical and chemical means has as yet been found by which sugar may be converted into alcohol. So far, therefore, the weight of evidence rests with PASTEUR, viz., that true fermentation is solely brought about by living organisms.

The organisms which cause the alcoholic fermentation are commonly known as *mycoderma cerevisiæ.* The term *Torulæ* has also been applied to the true yeast germs, to distinguish them from another kind of germs which are also found in the wort, and which cause, from the brewer's point of view, a diseased form of fermentation. These are called *Bacteria.*

The *bacteria* are very various in form. Some are tubes from 1-15,000 of an inch up to 1-2,000 in length, divided by a little septum or division in the middle into two equal parts. They are sometimes stationary, but as a rule they are darting about the liquid with great rapidity. The process of reproduction in the *bacteria* is generally that of simply dividing into halves.

The size of the *torulæ* vary from minute specks up to the 1-2,000th of an inch in length. Their mode of reproduction is by germination. First, a little projection appears on the cell, which gradually gets larger, and finally a bud is formed, which separates from the mother cell.

The German brewers have long thought that the *torula* cells were reproduced by a process of emission of spores, and that these spores were carried by carbonic acid through the gyles into the air.

PASTEUR has discovered a method of growing *torula* germs only, so that the brewer can have pure yeast, uncontaminated with *bacteria*, the "*maladie de ferment.*"

He directs a solution of sugar to be added to a sample of ordinary yeast. The yeast ferments, and after it has finished fermentation, or very nearly so, the supernatant liquor is to be poured off and a fresh solution of sugar added. This is repeated two or three times. During this process the cells become weak and wanting in vigour. They are then placed in a bottle or closed vessel, and a little wort which has been previously well boiled added, in order to reinvigorate them. A new crop of cells is thus obtained, containing no *bacteria.* The next stage in the process is to grow a larger crop of yeast. This is done by setting up fermentation with some of the pure yeast in a vessel cleansed by steam, and which is kept charged with carbonic acid, perfectly free from germs, to exclude all atmospheric spores.

Yeast can be kept very pure by taking care to ferment only at low temperatures. This may be done with such a portion only of the wort as is sufficient to yield enough yeast for the whole of the brewing. Care must be taken not to use the scum or the unsound and foul yeast that first comes off.

Yeast is very variable in its effects, according to the time of its production, its succeeding management, its age and condition; to excite energetic fermentation it cannot be too fresh. The best yeast is collected from pale gyles, near the close of the alcoholic fermentation, and after the first or second skimming. The first portions of yeast thrown off are not sufficiently solid, and besides generally contain some of the glutinous matter which has not been wholly transformed into yeast. It is therefore liable to undergo further oxidation, and to set up an acetous or putrefactive fermentation. It is needless to add that such yeast would be highly injurious, and ought to be avoided.

When collected as above described, it is sufficiently dense, contains no glutinous matter which has not undergone oxidation, and is, besides, wholly free from the old store or ferment added to the liquor in the beginning of the fermentation. It has also the great advantage (in accordance with PASTEUR'S theory) of having been entirely protected from contact with atmospheric germs during its formation. By using the yeast thus carefully prepared, a much less quantity of it will be effectual than of the other kinds which may be taken at random.

Yeast should be washed and pressed, and kept in a closed vessel and cold. German brewers, when they are not able to use it at once, press it, mix it with sugar, and put it into a vessel which is closed and kept cool. The state of the yeast should invariably be investigated by the microscope before using, that if it contains many *bacteria* it may be rejected.

Dr. C. GRAHAM gives the following ready method of ascertaining the comparative potential energy of samples of yeast. Take a sample of wort, using half a litre for each given experiment, and place this quantity of the same wort into the respective fermentation bottles. Then weigh 2 grammes of each sample of yeast after pressing them between blotting paper to remove the moisture (this is equal to about 2 lbs. per barrel), and add them to the respective test bottles. The apparatus in each case is then closed. It consists of a bottle with a short tube passing through the cork, but which does not go down to the liquid. It is connected by a piece of india-rubber to a long tube, which also passes through a cork into another bottle, but does not touch the liquid. In the second bottle there is a long tube which passes down to the bottom of the liquid, and then comes up and passes into a measure glass, and in the measure glass it also goes down to the bottom. When the action is started, fermentation is set up more or less vigorously, according to the energy of the yeast, and carbonic acid is produced. Now, carbonic acid may be taken with very great accuracy as a measure of the energy of the fermentation. The carbonic acid passing through this tube presses the top of the liquid in the second bottle, which is a saturated solution of common salt; the object of using which is, that this liquid shall not dissolve much carbonic acid. As it presses this, it drives some of the liquid into the graduated glass. The conditions of the experiments are the same in all the cases, so that it is easy to decide in the course of twelve hours to twenty-four as to the respective decomposing powers of the yeast. When the fermentations are started the bottles must be kept in the same place, so that they may be subject to the same temperature. (*Society of Arts Journal*, vol. xxii. p. 300.)

The principles of the vinous fermentation have already been described at sufficient length (see also ALCOHOL). It is worth observing, however, that there are various other species of chemical decompositions, commonly characterized by the term fermentation, in which by direct or indirect oxidation certain compounds are generated. According to the nature of the substances operated upon, one or more of these fermentations may be excited by the contact of a body undergoing the like decomposition. For instance, a compound in the state of the acetous or lactic fermentation, on being brought in contact with a solution of sugar, occasions the direct formation of either acetic or lactic acid in the liquid.

This being the case, it is evident that the greatest and most scrupulous care should be observed in selecting the "barm," or "store," which is employed to induce the vinous fermentation in the wort, lest it may have contracted any acidity or putrefaction, which would certainly prove detrimental to the beer, by setting up the lactic or acetic fermentation, and thus deteriorating its flavour, wholesomeness, and keeping properties.

The apparatus required for the fermentation are either circular tuns or squares, constructed of sheet-iron or Dantzic deal, and of a capacity suited to the quantity of materials employed; they are generally furnished with an attemperator, or pipe, through which either hot or cold water, as the temperature of the contents may be too high or too low, is transmitted. These vessels will be fully described later on.

The liquid is introduced into the fermenting tuns at a temperature varying from 54° to 64° Fahr. (12°·2 to 17°·7 C.), according to the practice of different brewers. In England the pitching heat is usually between 60° and 64° Fahr. (15° 5 to 17°·7 C.), or even higher; while in Scotland the temperature, except in some few cases, does not reach higher than 58° Fahr. (14°·4 C.). When the pitching heat is high, and the yeast is of a good quality and in sufficient abundance, the fermentation proceeds so rapidly and with such energy that it becomes ungovernable; some means must therefore be employed to check the heat. For this purpose coils of pipe, through which water circulates, are fitted up in the tun. Unless this is done the whole of the glutinous constituents of the gyle is not removed in the yeast, and the liquor does not cleanse satisfactorily, in consequence of an after fermentation which sets in, which is technically known as the "fret."

On the other hand, if the action proceeds sluggishly, so that the yeast remains in contact with the liquor at a temperature of 66° to 70° Fahr. (18°·8 to 21°·1 C.) for some time, then, in addition to the beer being ropy, it will retain the disagreeable taste of the yeast, that has to some extent entered upon the putrefactive fermentation. The beer is in this case termed "yeast bitten."

To guard against both these serious evils, it is necessary to be scrupulously careful that the store yeast is in a good and healthy condition, and also that the temperature is properly regulated, as well in reference to the bulk and gravity of the gyle, as to the state of the atmosphere. The practice observed by some brewers of beating the head of the yeast into the gyle, however it may seem to favour the operation, is not so indispensable as they would suppose; for if the action be engrafted in the liquid at the first, it will proceed with sufficient power to complete the work without the assistance offered by the new yeast being beaten into it.

Keeping these considerations in view, the brewer may discharge his worts into the fermenting vessels at from 58° to 64° Fahr. (12°·2 to 17°·7 C.), according to the conditions already alluded to; but before he proceeds he should ascertain the mean temperature of the air in the room, and note the real density of his gyle, and the quantity in barrels and firkins, so that he may be better able to judge of the rise of temperature, the degree of attenuation, and the waste suffered during the action; and above all, the proportion of yeast or "store" to be added at the commencement. Various circumstances tend to influence the quantity of yeast which ought to be added to the gyle; hence, to give a definite rule in this particular is out of the question. By studious attention and moderate experience the brewer will be able to master the difficulty, especially when it is borne in mind that the variation takes place, first and principally, with the quality of the store; secondly, with the degree of heat at which the malt had been dried, and the quality of the liquor used in mashing; thirdly, with the gravity of the worts; and fourthly, with the temperature of the liquor, and likewise that of the air at the time of pitching the tun.

When starting fermentation, if highly dried or patent malt has been used, the yeast must be added in larger proportion than if the worts were extracted from pale malt, for the constituents of the grain undergo decomposition, in consequence of which the proportion of gluten is considerably reduced in the extract; and to make up this deficiency of matter by which new ferment is formed, and the action of the original ferment invigorated, a larger proportion of yeast must be supplied in the first instance. The same precaution must be observed when the temperature of the gyle is low, and a large amount of extract is present. The temperature of the liquor and air at the period of fermenting will greatly influence the rapidity of the fermentation; for when the degree of heat is elevated, the matter of the gyle will more readily commingle.

When the gravity of the gyle is about 45 lbs. per barrel, and the temperature of setting 58° or 60° Fahr. (14°·4 to 15°·5 C.), the atmosphere being at the ordinary temperature and barometric pressure, provided the yeast be of good quality, about 2 to 2½ lbs. per barrel will be sufficient, and it may happen that this quantity may in some cases overstore the tun. In winter, on the contrary, the store per barrel is increased to 3, and sometimes 3½ lbs.; but then the heat of pitching is lower than in the preceding case.

When worts of 20, 25, 30, or 40 lbs. per barrel—the usual strength of the ordinary ales—are fermented, a less weight of store must be added in proportion as their density decreases.

The intervals of adding the yeast, like the various other operations in brewing, are different with most brewers, some preferring to add the total quantity at once, while others reserve a portion to be subsequently introduced in order to strengthen the fermentation. As in either case the results are satisfactory, the brewer must be left to his own discretion in this matter, being mindful, however, that it is necessary to have a healthy action inoculated in the gyle from the beginning, otherwise the fermentation will not be successful.

After the mixture of the yeast and gyle has been made some time, some minute bubbles of gas rise to the surface, and form on the sides of the vessels; as the operation advances, this ring of minute vesicles, or froth, as it is termed, becomes detached, and moves towards the centre, its place being in a short time occupied by another ring, which imitates its predecessor, and thus the rings succeed one another till the whole surface is covered.

As the decomposition of the sugar becomes more rapid, the liberation of carbonic acid is freer and more voluminous, and a hissing sound or effervescence is observed. The froth swells to a larger extent by retaining the carbonic acid in the viscid matter which rises to the top. At length the volume accumulated is so great that the tension of the yet imperfect yeast cannot restrain it, it bursts and causes inequalities in the head, which gives it the appearance which the brewer terms "rocks."

The froth, which hitherto was colourless, begins to be tinged yellow, and as the work proceeds it turns either to a lightish or brownish yellow; but it is a better sign of the fermentation if it remains of the former shade.

The yellowish brown colour is mainly due to the decomposition of a peculiar glucose compound with the resin of the hop. The glucose is broken up, and forms alcohol and carbonic acid, and at the same time the resinous matter which was previously associated with the sugar is liberated.

At this period of the process the head falls considerably, in consequence of the carbonic acid gas which accumulated during the preceding part of the operation overcoming the elasticity of the yeast and escaping; the newly-formed yeast becomes more dense and viscid, and the fermentation is much diminished. Were the head permitted to remain in contact with the liquor after this period, it would very soon precipitate, and probably, by itself entering upon a putrefactive decomposition, would give rise to the same in the liquor; at any rate, the disagreeable bitterness which characterizes stale or putrefying ferment would be discernible in the beer, and in this state, as already remarked, it is said to be yeast-bitten.

To prevent the pernicious effect of yeast-bite the ferment is skimmed off, and the fermentation is also checked so as to prevent it from passing the desired limits; many brewers, however, take off only the top surface, beat the remainder into the liquor, and continue the fermentation with renewed vigour, till all the albuminous matters are separated in the form of yeast, and the greatest part of the sugar has been converted into alcohol and carbonic acid. Such is the treatment usually applied to exported ales, or bitter beers that are reserved for store.

Yeast-bite is due to the action of the alcohol formed, not upon the living but upon the dead yeast cells, and upon the resinous matter separated in the decomposition of the glucose.

After a time the fermentation is attended of course with an attenuation of the wort. The amount of attenuation in this country is to the extent of about two-thirds of the original gravity of the wort; in some cases it is even carried down to three-fourths. The amount of work done depends of course to some extent upon the amount of yeast produced, and the amount of yeast production varies with the fermentation itself. It depends, in the first place, upon the temperature, for the higher the temperature within a given range, the more active is the production of the cells; it depends also upon the amount of hops used, for the less hop the more vigorous the cell growth and chemical decomposition. It depends also upon the amount of glutinous matter found in a soluble condition in the wort, *i.e.*, the amount of *food* supplied to the yeast germs. It also depends upon the amount of kiln drying to which the malt has been originally submitted; and lastly, it depends on the actual reproductive energy of the yeast cell itself.

When the fermentation flags, various plans are adopted to overcome the difficulty of the fermentation standing still. One of the simplest plans is to add more yeast, but probably enough yeast may have already been added. The other plan which is very much used is to add some ground malt. A large quantity of soluble albuminous matter is thus supplied, and the probabilities are that the action of the ground malt is not that it supplies sugar, because there is enough there, but that it supplies the yeast with a quantity of readily assimilable albuminous matter.

In brewing mild ales it is necessary to have a certain quantity of the sugar unattenuated, in order to give more or less sweetness to the beverage, and therefore the barm is skimmed off, as above stated, to check the fermentation, and attain the end proposed.

Horace Brown, in his researches on the influence of pressure on fermentation, has recently found that hydrogen and nitrogen gases are invariably liberated, and a certain amount of acetic acid produced. And this although he took special precautions that there should be no possible access of oxygen to the liquid. The presence of this hydrogen and nitrogen indicate that the decomposition is not so simple as had previously been supposed. Brown performed a great number of experiments, and derived the following conclusions from them :—In the first place, the fermentation products are not only alcohol, carbonic acid, glycerine, succinic acid, and acetic acid, but there are also hydrogen and nitrogen gases given off. Secondly, that as the amount of nitrogen is decreased the amount of hydrogen is increased. (The nitrogen is of course the product of the decomposition of albuminous matter). When the amount of hydrogen is increased in this way, he also observed an increase in the amount of aldehyde and in the amount of acetic acid. The formula of aldehyde and alcohol are C_2H_4O and C_2H_6O. By taking away two atoms of hydrogen from alcohol aldehyde is formed; and by adding one atom of oxygen to the aldehyde acetic acid, C_2H_4, is obtained. Thirdly, he found that water is decomposed by the yeast organisms in the process, and that their power to decompose water was facilitated by a reduction of the pressure. Fourthly, he observed that on reduction of the pressure a less amount of sugar was decomposed, but that there was a greater amount of that which was decomposed converted into acetic acid and into aldehyde.

Fermenting Tuns.—When the wort is run into the fermenting tun, yeast is added to induce fermentation. The fermenting tun must be of sufficient capacity to contain the whole of one brewing or "gyle," with additional depth to allow room for the yeast formed in fermentation. The proportions of the fermenting tun are not very important. Most brewers prefer it to be a cube. It may be either circular or square. It is generally made of fir, though during the last few years slate has frequently been used on the score of cleanliness. Glass has recently been tried, but there is considerable difficulty in keeping it sound.

As it is very important to keep an even temperature during fermentation, every fermenting tun should have an attemperator, consisting of coils of tinned copper pipe, usually supported by brackets from the sides of the tun, one above the other, or side by side. Two or more coils of pipe are required, according to the size of the tun, to get the requisite surface. The brackets are sometimes made of galvanized iron, but many brewers prefer keeping iron out of fermenting tuns, and therefore use tinned gunmetal brackets. Occasionally, and especially in small fermenting tuns, portable attemperators are used, which are raised or lowered at pleasure by a cord or chain.

The attemperator is supplied with cold liquor, and when the temperature of the beer is rising a small stream is allowed to flow through the pipes; the main object of the attemperator being to check an increase of temperature, as if the beer is permitted to get too hot the mischief is done, and is not rectified by its being cooled down afterwards.

According to the old method of brewing the beer was kept in the fermenting tuns for about three days, and the fermentation was afterwards completed in cleansing casks (these will presently be more particularly described); but of late years "skimming" has much come into use, by which method the fermentation is completed, or very nearly so, in the fermenting tun.

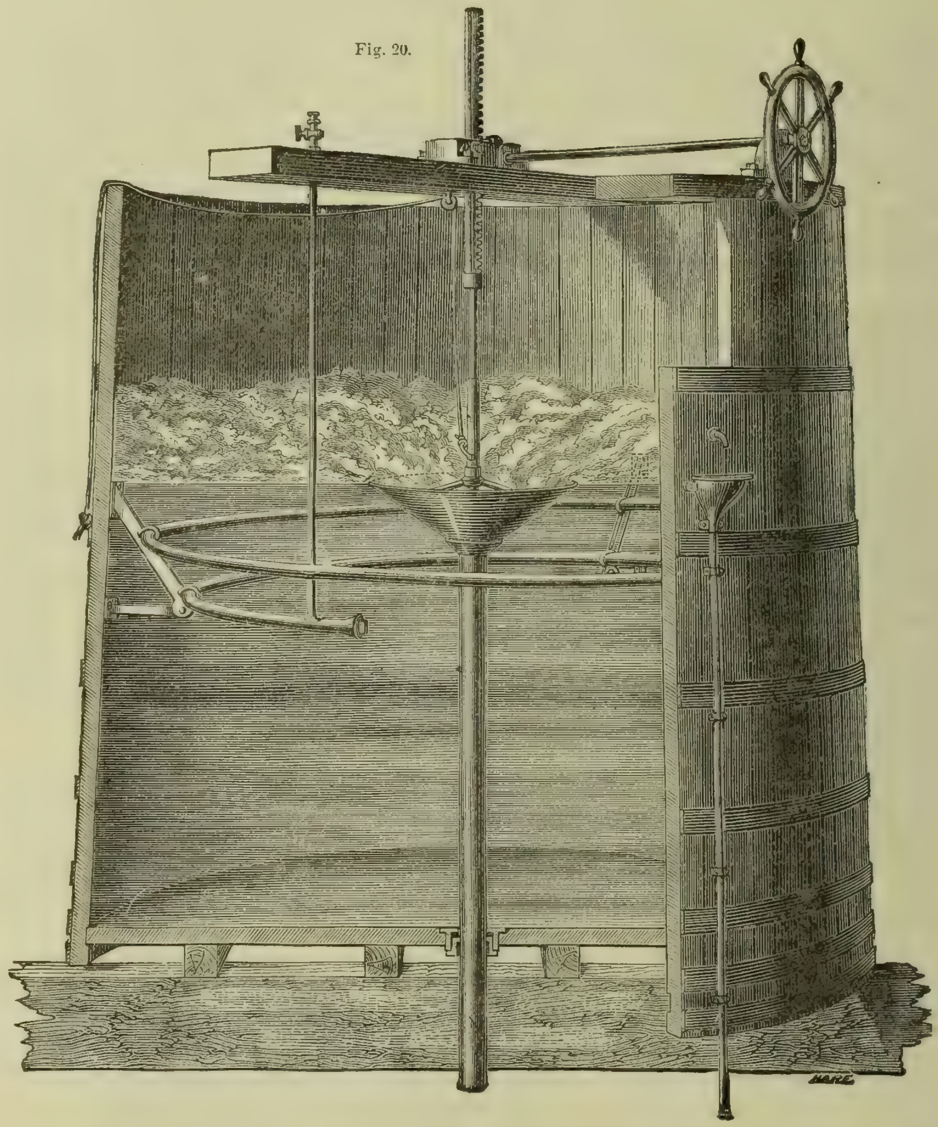
"Skimming" consists in removing from the surface the yeast that has formed; this may be done by hand, but it is an unsatisfactory method. The best mode of clearing away the scum is by the skimming apparatus represented in Fig. 20, which effectually accomplishes the operation with cleanliness, certainty, and ease.

The apparatus consists of a tinned copper basin with a valve in the centre, and a turned brass tube which works in a stuffing box fixed in the bottom of the tun. The whole of the apparatus is raised or lowered by means of a rack and pinion, or a screw, worked by a handwheel at the front of the tun. The edge of the basin is thus so set that it is very slightly above the level of the beer. As the yeast forms it falls over into the copper basin, and is let off at pleasure by pulling a cord attached to the valve, it then passes down the brass tube into a yeast trough below.

Fig. 20 shows a fermenting tun with fixed attemperator and skimming apparatus. The number of fermenting tuns required in a brewery is regulated by the frequency of brewing. Where skimming is not adopted the beer remains in the fermenting tun about three days; but if skimming is practised, for about double that time. The position of the fermenting tuns must be such that the beer will run into them from the refrigerators; and they must be high enough from the ground to give height underneath for the cleansing casks. Each fermenting tun is provided with a discharge cock, through which the beer, when properly fermented, is run off.

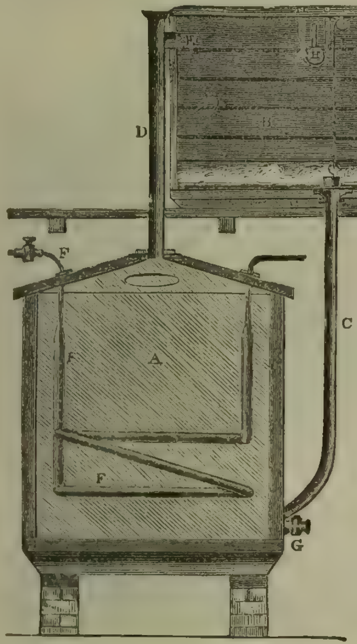
The double fermenting square is a contrivance which has acquired some celebrity in Yorkshire and the adjoining counties. It consists of an inner close square, with an exit pipe from the cover, through which the barm escapes. In this the worts are inoculated with the ferment, and the space between its walls and those of the exterior square is filled with cold water, by which the temperature of the enclosed liquor is maintained at a low point, and hence the fermentation, though slow, is more sure in its effects. It is controlled, however, with much difficulty in the summer time, when cistern or surface water acquires a heat of between 60° and 70° Fahr. (15°·5 to 21°·1 C.), unless there is sufficient spring water at command. The brewer endeavours to keep the fermentation at about 62° to 64° Fahr. (16°·6 to 17°·7 C.) till the attenuation has been continued as far as is desirable; then, by transmitting cold water into the exterior chamber, as well as through an attemperating pipe placed in the liquor, he reduces the heat to about 56° Fahr. (13°·3), at which degree it is maintained during the cleansing.

Fig. 20.



The annexed simple arrangement, Fig. 21, represents the fermenting square of Messrs. Walker and Son, of Warrington, Lancashire. It consists of two squares, both air-tight; one, A, in which the fermentation is carried on, and the other, B, for collecting the discharged yeast. Both are connected by a pipe, C, which descends from the bottom of B and enters A at the front near the base. Through this pipe the gyle, as well as the yeast, is admitted into the square, completely filling it; well-fermented ale is then poured in, till there is a layer of about 2 inches in depth on the bottom of the yeast-receiver. As soon as the fermentation commences, and the yeast, as yet frothy and partially formed, begins to be discharged, it rises through the pipe, D, issuing from the top of the bevelled cover, and is discharged into the yeast-receiver at E. As the semifluid matter comes off from the lower vessel, the layer of beer in the yeast-receiver descends in its stead, and maintains the proper level, leaving the bottom of the latter still covered to the depth of 1 or 2 inches by the liquor received from the lower tun, and thus preventing the froth from again passing into it. In this way the operation is conducted till finished. When the heat of the liquor is too high, it is controlled by the transmission of cold water through the attemperating pipe, F. Another cylinder, H, through which a stream of cold water is passed, keeps the air in the covered yeast-receiver sufficiently reduced in temperature, thereby arresting to some extent the evolution of the carbonic acid gas arising from the action of the fermentation. This, to all who are conversant with the subject, is known to be very valuable in securing the soundness of the beer, and giving it a tone of warmth, besides rendering it pleasant and agreeable to the palate.

Fig. 21.



At the termination of the fermentation the yeast, which is accumulated entirely in the square, B, is collected by drawing off the layer of liquor which covers the bottom of this vessel, by means of a hose attached to a pipe, seen at *a*; and when this is done the barm is brushed out through a plug-hole near one of the corners, and passed along a hose into proper vessels. Should the yeast accumulate in great abundance in consequence of an excess of gluten in the gyle, then, by the same course as the preceding, it may be swept out and the ale drawn off, pumped up once more, and the fermentation continued till finished.

The heat of the fermenting liquor is under complete control, and may be retained at any degree, provided well-water is at hand.

This system of fermentation dispenses with the watching and hand labour usually required, and saves an immense amount of space in fermenting a large quantity, on account of the compactness of the apparatus. At the close of the operation the liquor, after being cooled by means of the attemperating pipe, F, is ready to be drawn off through the tap, G, into barrels or hogsheads, and at once sent to the consumers, in consequence of the yeast being continually removed during the operation. Messrs. WALKER use 12 ounces of barm to each barrel of wort.

Another great advantage of this system is found in the fact that no such taint as "yeast-bite" can ever be discerned in the liquor.

It has been shown on several occasions that, when the vinous fermentation takes place in a liquor, it is always succeeded, provided the liquor be left to itself, by the acetous fermentation. It is the same in the present instance; for if the fermented wort were allowed to repose after the first action has ceased and the product clarified, it would in a very short time become again turbid, absorb oxygen, eviscerate a mucilaginous matter (*mother of vinegar*), and turn sour. This further fermentation is prevented by the cleansing process.

Having thus enumerated the principal methods of inducing and regulating the fermentation, the next process in brewing is now entered upon.

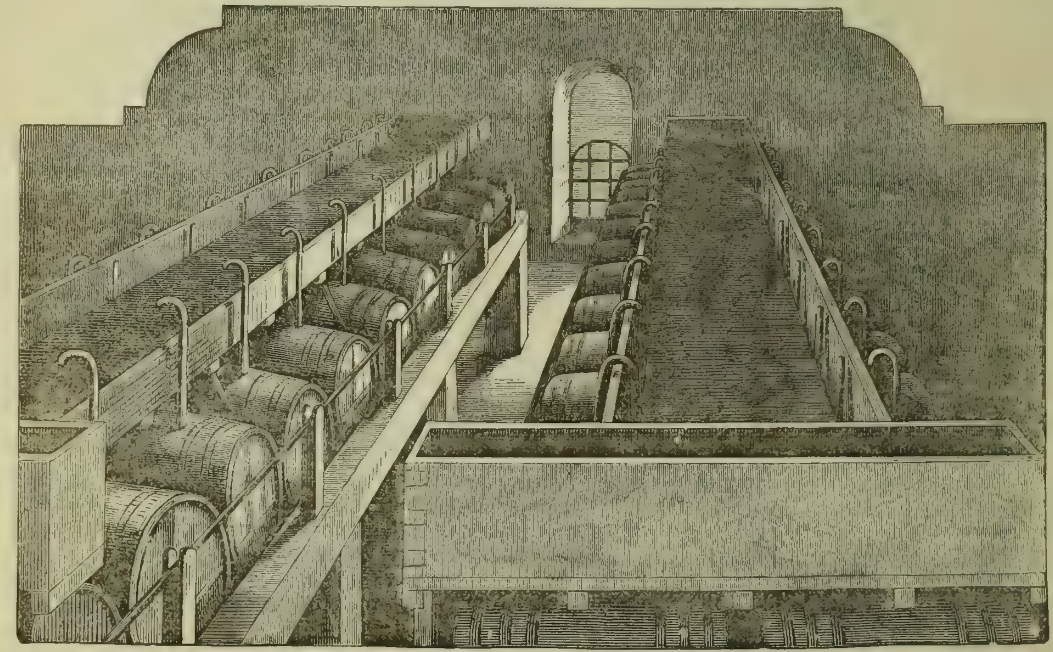
Cleansing.—After the fermentation in the tun has flagged, and the chief portion of the yeast has been removed by skimming or otherwise, particles of yeast and glutinous matter still remain held in mechanical suspension in the body of the beverage, and give it a muddy appearance. Could these be even removed by filtration the liquid would still appear muddy, since the fermentation has not completely ceased; and as long as this lasts fresh particles of yeast will be generated, and these will keep the liquid turbid and impure.

"Cleansing" is effected in a variety of ways; the oldest method, which is still extensively practised, is to run the beer from the fermenting tun by means of a hose into ordinary casks laid side by side on a trough, or stillion, about 2 feet high. The beer remains in these casks for several days, the bunghole being left often, and through it what little yeast remains in the beer works out and falls into the stillion. When the discharge of yeast ceases, the beer is ready to be bunged up and put into store. It may here be mentioned that beer is sometimes pumped from these casks and stored in large vats; but that system is now getting very much out of use, as the popular taste is more for mild than old beer.

The cleansing, when properly performed, is a very important stage; the distribution of the attenuated liquid into small portions has the effect of reducing the fermenting action considerably—so much so, that if the attenuation has not been sufficiently advanced at the time of racking off into the cleansing vessels, very little can be effected in them, and the liquor will remain too sweet. To prevent this, many brewers either briskly agitate the contents of the fermenting square, to raise the yeast which may have been deposited on the bottom, or add a fresh quantity of the ferment to it, and rummage the whole with an apparatus fitted in the tun for the purpose, or by any other contrivance. In either case, the object is to give the ferment a fresh stimulus, in order to counteract in some degree the checking influence of the racking into small quantities, whereby the temperature and other conditions that aid in converting the sugar into alcohol are not a little reduced. It would, however, be better to push the fermentation so far in the tun, that only enough of saccharine matter will remain to give to the liquor sufficient body, and also, by its slow fermentation, develop so much carbonic acid as to keep it sparkling and refreshing.

In the extensive breweries of Messrs. BASS and ALLSOPP the cleansing is very effectually performed, and for this reason a description of their method will here be given. As already stated, the cleansing has for its object the arresting of the fermentation and the separation of the yeast, and this is effected by transferring the beer into smaller vessels, where it remains till the clarification is complete.

Fig. 22.



At the above firms a number of casks, amounting to 800 or 900, each capable of holding four to five barrels, are placed in the cleansing-room. These are suspended in sets of ten or twelve on a substantial frame, so as to admit of a free revolution of the casks on their axes. Above these a large wide open trough—the yeast trough—is placed, with which each of the casks beneath communicates, first, by a movable or sliding tube, and secondly, by a head pipe, usually called a "swan-neck;" the former connection can be cut off at pleasure by a wooden plug. Diametrically opposite these two outlets a tap is screwed into the casks, and through this the liquor is drawn off when ready for racking. Immediately below these taps another trough is erected along the whole range, and the liquor is by this means conducted into the racking squares. At one end of the superior trough there is a small reservoir, capable of holding 5 or 6 barrels of liquor, and called the "feeder," in consequence of its being connected with each of the casks by a small pipe running parallel with their ends, and branching off into each; by this means the liquor which separates by evaporation, and also the yeast, are replaced from the reservoir.

Fig. 22 more fully explains this arrangement.

The following is the method of working the apparatus:—The ale to be cleansed is pumped into the large yeast trough, and then run into the casks through the sliding tubes; when the cask is quite full this communication is stopped up with the wooden plug mentioned before, leaving only the swan-neck outlet free. Through this pipe the froth arising from the fermentation forces its way, and is transferred to the yeast trough, where the yeast is deposited.

To keep the casks full, and to enable the froth to rise to the yeast tun, a quantity of liquor is put into the reservoir, and thence conducted into the casks by the pipe already mentioned. After the fermentation has continued in this state for one or two days, it apparently subsides altogether; the contents are then permitted to remain at rest for a few days longer, for the purpose of affording any yeast that may not have ascended to the trough, time to precipitate to the bottom. The clear ale is then drawn off by means of the screw tap inserted in the lower part of the casks. By turning this tap the interior sucker is so far elevated as to be above the dregs, and therefore none of the impurities are carried off in the liquor, but remain in the casks.

The system of cleansing by union cleansing casks, as commonly employed, is shown in Figs. 23 and 24. The casks usually hold about three barrels each, and a sufficient number of them is arranged in each set to contain one brewing. The casks are mounted end to end in double rows, on a wooden frame about 2 or 3 feet from the floor. Each cask has on both heads an iron cross with a projection which rests on an iron bearing screwed to the wooden frame, so that it may revolve after the manner of a churn. The bunghole of the cask is upwards, and in it is inserted a turned copper "swan neck" pipe, about 2 feet long, which turns over into a wooden yeast trough that runs down the whole length of the set of casks. At the end of the yeast trough is a feed back, into which the beer runs from the fermenting tun. From the feed back run two copper pipes, each along the heads of each row of casks. At each cask there is a cock in the main, through which the beer is admitted into the cask. The casks being filled, the quantity of beer necessary to fill up the casks from time to time is left in the feed back. The yeast works up through the "swan neck" pipes, and falls into the yeast stillion. At the bottom of each cask, directly underneath the bunghole, there is a discharge cock, through which the beer, when finished, is delivered into a wooden or copper trough that runs underneath the casks. The beer then runs into a settling back, or racking vessel, where it is allowed to settle for a short time before being drawn off into casks for sending out. By detaching the connections from union casks they can be washed in their places by having some liquor run into them, and then being revolved.

Fig. 23.

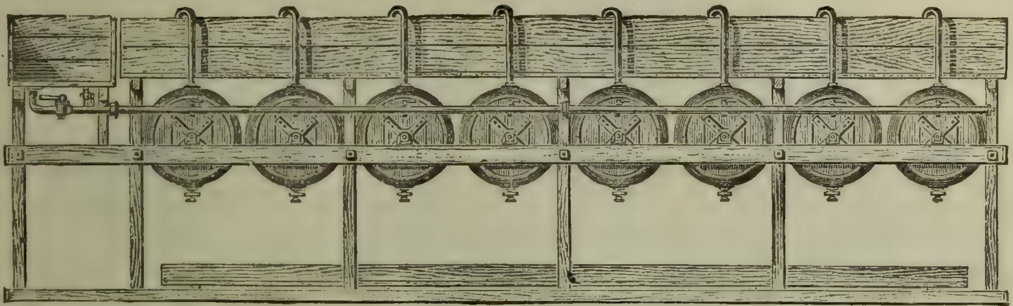


Fig. 24.

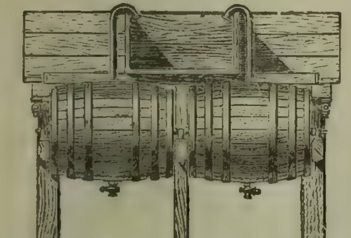
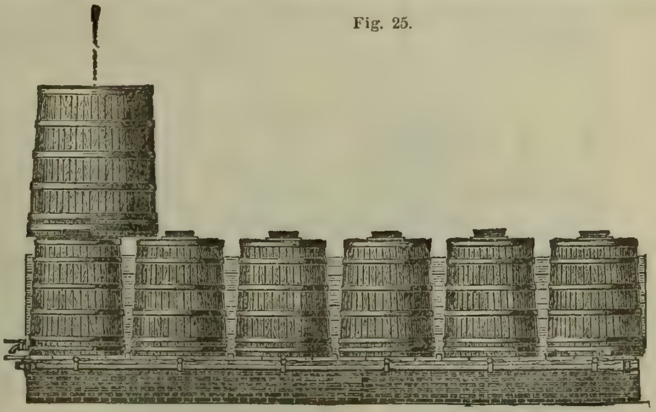


Fig. 25.



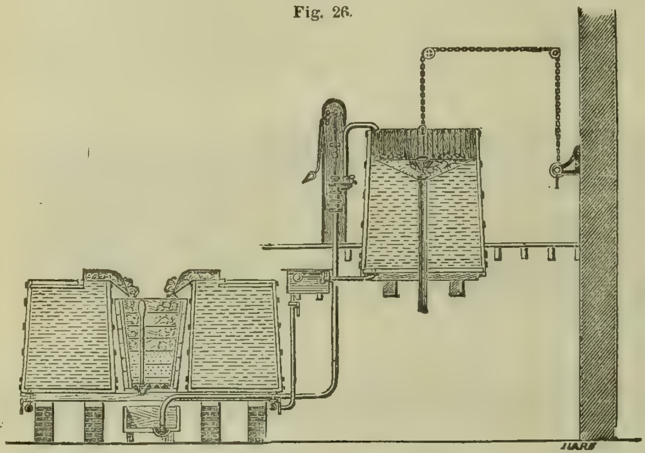
Union cleansing casks are not very much used, except in the breweries at Burton-on-Trent; but there they are extensively used, Messrs. BASS & Co., Messrs. ALLSOPP & SONS, and other large brewers there, having many hundreds of them.

Another system of cleansing, principally adopted by the large porter brewers, is to use pontos (Figs. 25 and 26). These are vessels made in the shape of vats, and containing from four to ten barrels each. The pontos are placed in a double row, with a yeast stillion between them. The beer is run into the pontos, and the yeast works out through an opening in the head into the stillion. The feed back is a similar vessel, and furnished with a skimming apparatus the same as that described for fermenting tuns.

In other respects pontos are worked in precisely the same manner as union cleansing casks. The general arrangement and mode of working can be seen by a glance at the accompanying Figs. 25 and 26.

A simplified form of the principle of union cleansing casks is shown in Fig. 27. It is entirely self-acting, and by its use manual labour is dispensed with in tunning the beer and filling up. By this method also ordinary casks may be used. Each cask is furnished with a brass nozzle fitted into the bunghole, from which a small copper pipe descends to nearly the bottom of the cask. At the upper part of the pipe is attached a short piece of india-rubber hose, which slips on to the nose of a cock fixed in the yeast stillion placed above the casks. From the same nozzle a tinned copper "swan-neck" pipe stands up and turns into the stillion. The beer, when ready for cleansing, is turned into the stillion. As many casks as may be desired are charged at one time, and are kept filled up until the beer has done working, the pipes in the casks carrying the beer towards the bottom, and the swan-neck pipes delivering the yeast into the stillion. The cost of this apparatus is very considerably less than that of union cleansing casks, and its action is generally considered to be as good.

Fig. 26.

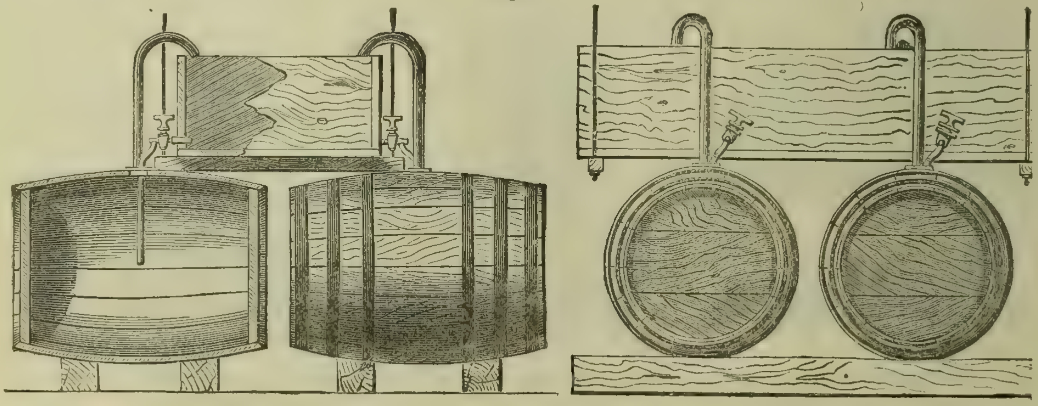


This system of cleansing may be extended (as shown in Fig. 28) by adding a tinned copper main, into which to screw the feed cocks, instead of putting them direct into the stillion. The main is supplied from a feed back at the end of the stillion, and the casks are kept filled up with bright beer instead of with beer from the yeast stillion. This brings the system to very nearly the same thing as union cleansing casks, but still at a greatly reduced cost, with the further advantage that ordinary casks are used. If the casks are used solely for this purpose, they can be brought still nearer to the arrangement of union cleansing casks by hanging them on crosses resting on a frame, as shown in Fig. 29.

This completes the ordinary process of brewing.

It often happens that the yeasty matter or grounds disseminated through the ale in the casks does not precipitate, and the consequence is that it causes the muddiness already noticed to remain. It appears that the composition of the water has a very great influence upon the cleansing of the ale, for when lime compounds are present, the action of the salts inherent in the malt and dissolved in the worts causes a double decomposition, by which a lime salt is precipitated, and this carries with it the impurities to be removed. The Burton water is remarkable for its adaptation to brewing in this particular, namely, that no finings or other extraneous matters need be added to the fermented wort, in order to produce a clear transparent beverage.

Fig. 27.



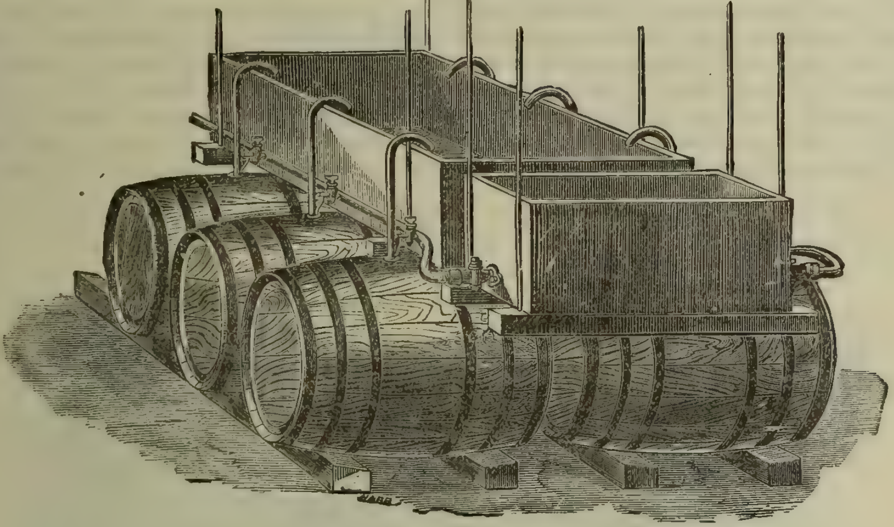
With the exception of chloride of lime, bisulphite of lime, and quicklime, the less brewers have to do with chemicals the better.

Simple quicklime, or some such alkali, mixed with the neutral or acid sulphite of lime, is useful when the beer turns hard, but it is far better not to produce hard sour ale.

In a great many instances, where recourse is had to the use of finings, a little more care bestowed upon the preceding operations would do away with the necessity of using them, and it is very questionable whether, in any case, finings or precipitating agents for removing the impurities should be employed.

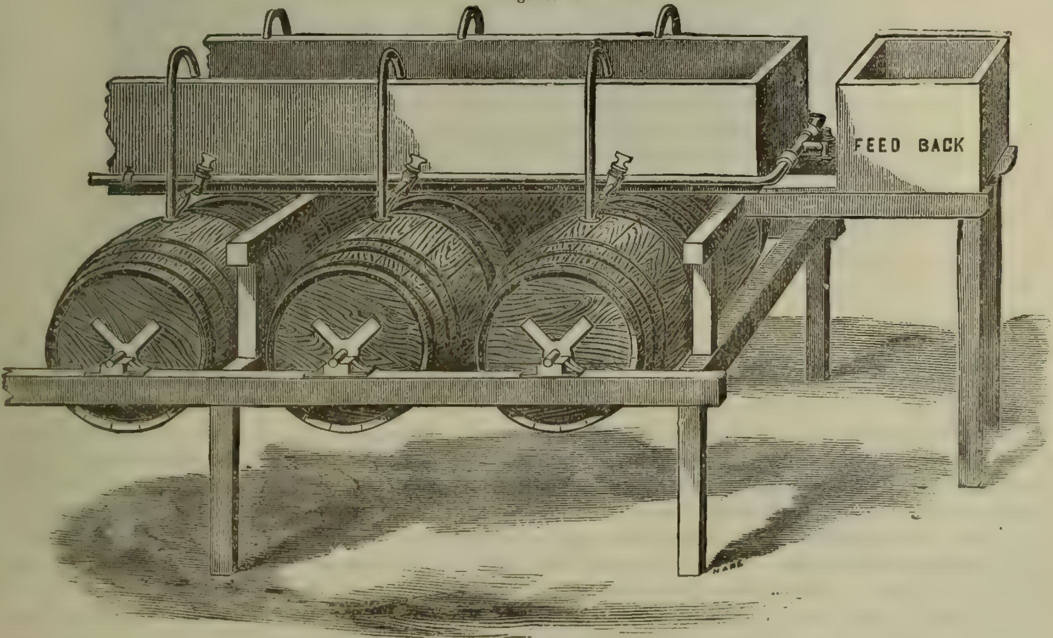
The substance most generally used for this purpose is isinglass, which is dissolved in sour beer, and then strained through a hair sieve. The consistence of the solution should be that of a pretty thick mucilage. When a small quantity of it is poured into a cask of the ale or beer, the grounds separate in a very short time, and the liquor remains bright, and free from mechanical impurities. One pound of isinglass will make twelve gallons of finings.

Fig. 28.



With respect to the action of the fining liquor on the ale, no very satisfactory explanation can be given. Many regard it as spreading over the surface of the liquor, and forming, as it were, a network, which, as it sinks, envelopes the whole of the mechanically suspended matters, and carries them with it to the bottom, while the supernatant liquor remains clear; others, again, look upon the floating impurity as being held by the cohesive attraction of the surrounding fluid in such a condition that, whilst the affinity of the latter is not so powerful as to cause solution, it is nevertheless so strong as to keep it suspended or in

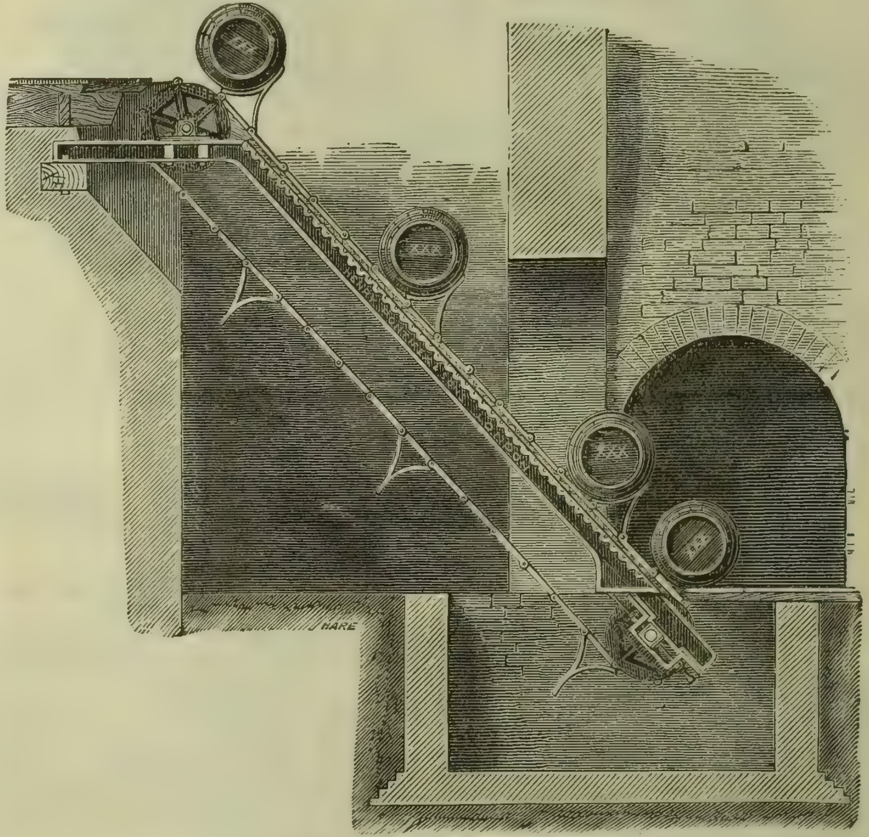
Fig. 29.



combination; and the fining is supposed to operate by rendering the affinity of the solution for the grounds less, in consequence of being itself dissolved, while it is affirmed that the least derangement of this power is sufficient to insure their subsidence; while some think that, from the fining being lighter, it immediately ascends, carrying with it the deteriorating ingredient, leaving the beer in a clear state. It is evident, however, that there must be a combination of the yeasty matter with the isinglass (whether of a mechanical or chemical nature is not ascertained). This is more obvious from the circumstance, that other substances, such as glue, which seemingly partake of the same properties, will not effect this purification. It would seem also, that the great divisibility of the matter in the beer, together with a more or less cohesive affinity of the liquid for it, is the cause of its retention; and if this cohesion be in some measure destroyed, by either precipitating the substance, or bringing the particles closer together so that they may combine from the effect of the attraction among themselves, the liquid will then readily clarify. If when the isinglass solution is added no precipitate occurs, it may be made to take place by adding a little infusion of hops.

Many other bodies, such as albumen of eggs, or serum of blood, react on muddy ale like isinglass. DUNOVAN states that alum, in the proportion of one ounce to the hogshead, will purify it thoroughly in a very short time, and without leaving any perceptible taste; he further says that the dried stomach of the cod-fish, called "sounds," on being macerated in sour beer, affords a fining liquid equal in most respects to the more expensive isinglass. Eight or ten days are required to dissolve the sounds perfectly, when nothing remains but a small quantity of impurities, which straining through a cloth filter will remove. More or less of this solution is required, according to the purity of the liquor; but it is certain that, *ceteris paribus*, the less either of this or of isinglass liquid that is used the better, for these substances tend to communicate a flat taste to the beer, and prevent it from carrying a good head. When sounds are used, it is better to employ them in summer than in winter; in the latter season isinglass is to be preferred.

Fig. 30.



Very many persons, after the fermentation has ceased, instead of cleansing in the way above mentioned, add a fresh quantity of hops, and leave them in contact with the liquor till the whole of the yeasty substance is carried down with them as they subside. The ale, in this case, is improved to some extent by the addition of the fresh hops; but where the custom is to introduce some of the spent hops from a previous operation, the practice is productive of more injury than benefit.

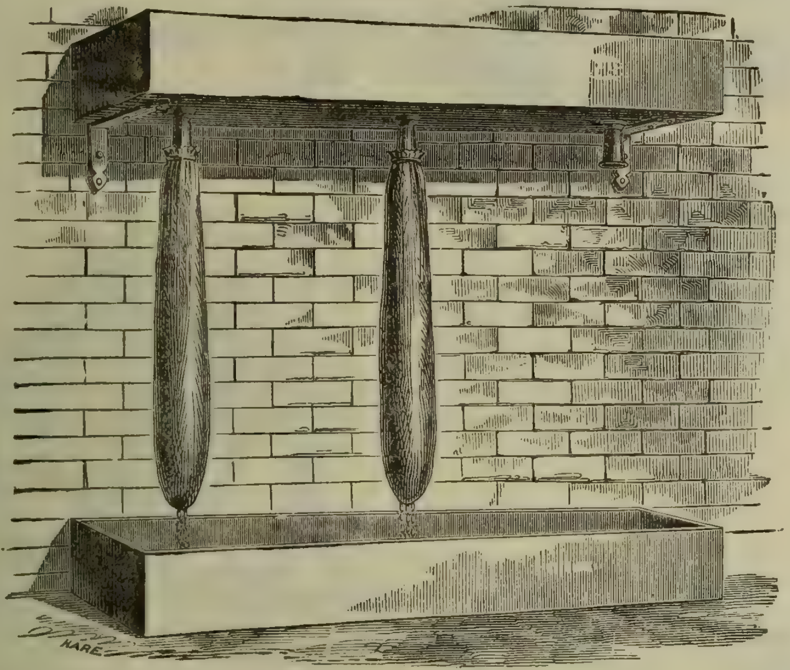
After the clarification, the ale is racked off into store vats, or barrels, to be sent to the consumers; and in doing so much attention must be directed to the casks and vessels, observing carefully that they are wholly free from any bad taste, smell, or putrid matter, which would contaminate the ale.

Beer is stored by preference in underground cellars for the sake of securing a cool temperature; and in many cases a cask-lowering machine is used for lowering the beer into the cellar. The best form consists of a platform working against a plate attached to the wall. The platform is suspended by means of counterpoise weights. When the platform is up, it is level with the floor from which the casks are to be taken. When the casks are rolled on to the platform, their weight causes it to descend, and when it reaches the floor of the cellar it strikes on a spring which jerks the casks off, and the counterpoise weights immediately bring the platform up to its original position.

To bring the beer up from the cellar it is customary to use a cask-raising machine (Fig. 30). This commonly consists of two strong wrought-iron endless chains, furnished with arms, running over pulleys driven by steam power, which pass through slots cut in the floor, and pick up the casks rolled to the foot of the elevator at the bottom of the cellar, and deliver them at the required height.

Some twenty years ago yeast was considered as almost refuse, but more recently brewers have become aware that it may be profitably utilized. This cannot be done unless the beer mixed with the yeast be separated from it, and the yeast rendered very nearly dry. Several machines for pressing yeast have been designed; the most successful are those patented by Messrs. Needham & Kite and Mr. G. A. Waller.

Fig. 31.

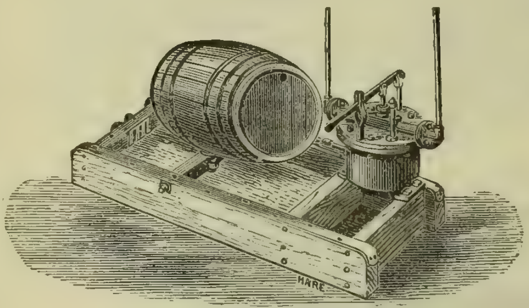


A simple but very efficient apparatus for filtering all kinds of thick beer and yeast is shown in Fig. 31. It consists of an upper trough, into which the yeast or other matter to be filtered is put. Into this trough one or more brass nozzles are screwed. To each nozzle is attached, by a brass ring, two bags, one within the other, the inner bag being the filtering medium. The inner bag is folded three or four times. The outer bag is only about half the diameter of the inner one; therefore as the yeast runs into the inner bag, it is swelled out and pressed against the outer bag. The inner bag is of course sewed up at the bottom, but the outer one is not completely closed up, and the filtered beer percolates through the bag into the trough below. As this apparatus is very inexpensive and requires no attention while at work, it is especially suitable for small breweries. When the beer ceases to run from the bag, the brass nozzle is unscrewed from the trough, and the bags taken off and washed.

In 1875 Thomas Ellis patented a process for the purification and preservation of yeast, which bids fair to make yeast a really valuable commodity to brewers. By his process the bitter is extracted from the yeast, and the yeast is granulated to a perfectly dry state, and will retain its fermentative powers unimpaired for years. It is evident that this process must be of very great value, since it will enable yeast to be exported and used for a variety of purposes for which it has been hitherto unavailable.

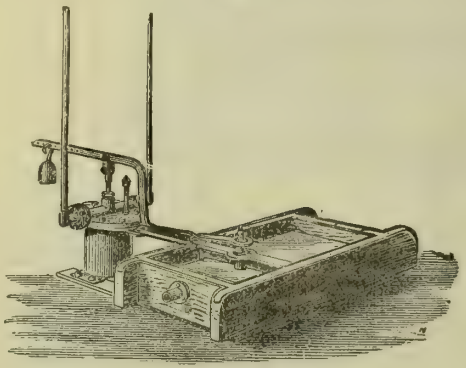
It is most essential that the casks in which beer is stored or sent out should be perfectly clean, and brewers are usually very particular on this point. Several methods of washing casks are used. The old plan is to about one-third fill the cask with hot liquor, bung it up, and roll it about for several minutes. Sometimes an iron chain is inserted into the cask at the bunghole; this scrapes off some of the dirt when the cask is agitated, but it is a tedious and laborious operation.

Fig. 32.



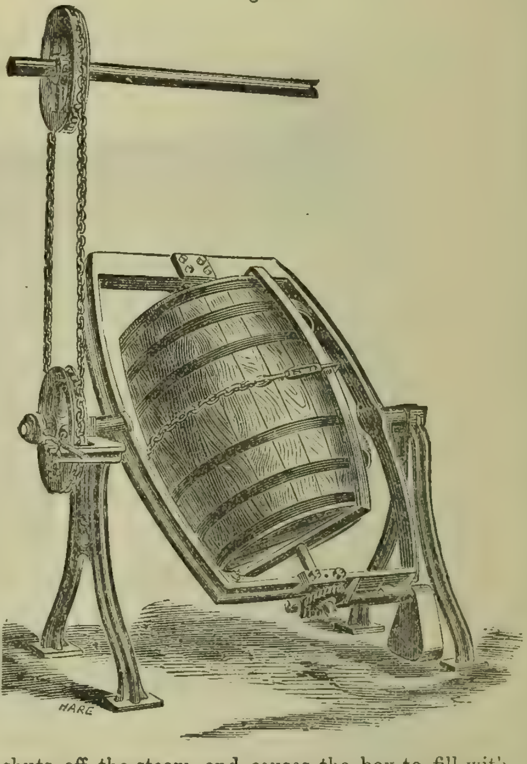
An apparatus, patented by Messrs. C. & F. Pontifex in 1871, not only cleans the casks in a thoroughly efficient manner, but also effects a great saving in labour, and in the quantity of hot water used. It is shown in Fig. 32. The cask cleaner consists of an iron feed-box (which holds the exact quantity of water required to wash the cask), connected by a pipe to a nozzle fixed across a trough or stillion. Steam and hot water are supplied to the feed-box, which has three gun-metal valves in it, one for the hot water, another for the inlet of steam, and a third attached to the exit pipe to the nozzle; these are all worked simultaneously by the lever on the top of the box. When the apparatus is at rest, the water valve is open, and the steam valve and the exit valve are closed; the hot water, therefore, runs into the feed-box and fills it. The cask to be washed is then placed upon the nozzle, which is perforated with several holes, and is large enough to project through the bunghole of the cask. The lever on the feed-box is then raised; thus shutting the inlet water valve, and opening the steam valve and the exit valve. The pressure of the steam, which is taken direct from the steam boiler, forces the water from the feed-box through the exit pipe and nozzle into the cask. When all the water has been delivered, the steam blows into the cask through the water and completes the washing. By pressing down the lever the steam is then shut off, the delivery to the nozzle is closed, and the water inlet is opened, upon which the feed-box again fills with water, while the cask just washed is taken off and another one put on the nozzle. From 60 to 100 casks per hour may be thoroughly washed by one of these machines.

Fig. 33.



This machine is sometimes fitted with a self-acting arrangement, by which the weight of the cask sets the apparatus in action, and removing the cask shuts off the steam, and causes the box to fill with water ready for the next cask, as described above. The self-acting arrangement is effected as follows:—The feed-box is placed at the back of the stillion or trough (Fig. 33), and the lever for working the valves is brought to the nozzle on which the cask is placed; therefore, when the cask is placed on the nozzle it presses down the lever, and puts the apparatus in action, as described. This apparatus is extensively used and highly successful.

Fig 34.



When casks are very foul from having been long empty, more thorough means are necessary for washing them. Sometimes the casks are unheaded and scrubbed out. Several machines for washing such casks have been designed: two well-known and successful ones may be here described. Fig. 34 shows a

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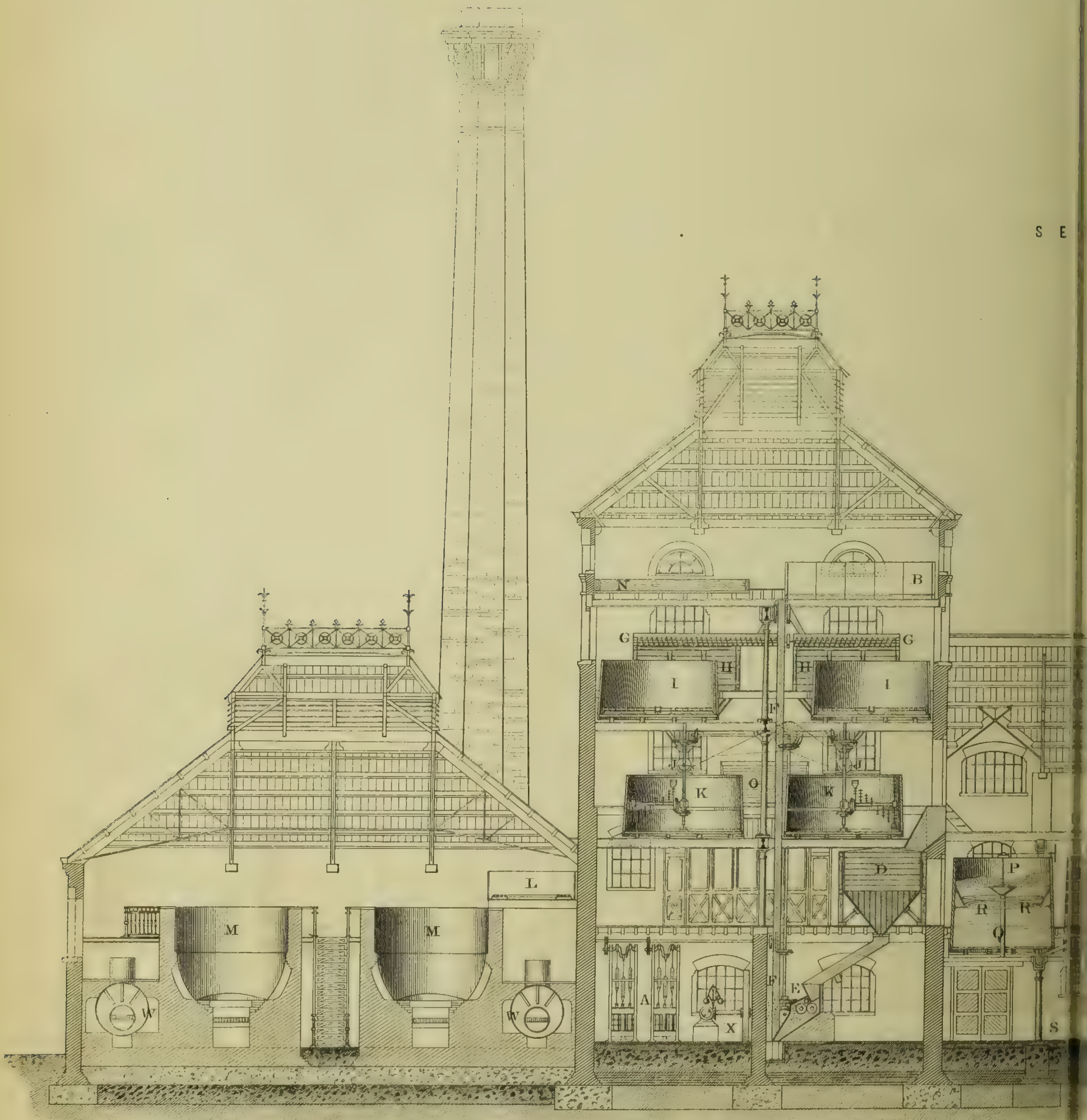


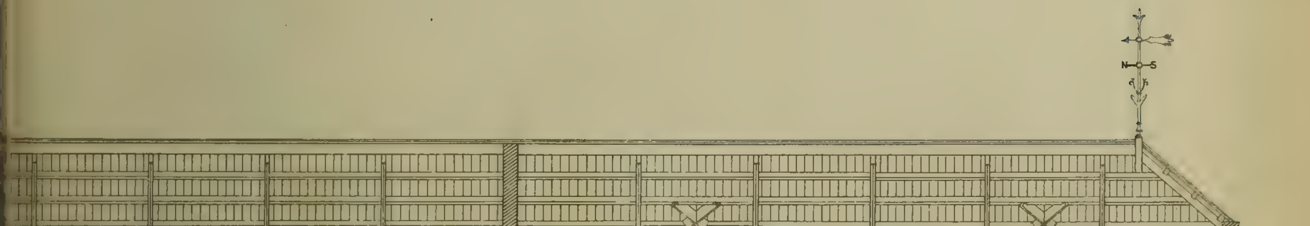
J. B LIPPINCOT

A *Pumps.* B *Cold Liquor Back.* C *Malt Store.* D *Malt Hopper.* E *Malt Rolls.* F *Elevator.* G *Malt Screws.* H *Gr*
O *Refrigerator.* P *Fermenting Tuns.* Q *Skimming Apparatus.* R *Attemperator.* S *Tun Room.* T *Union Cleansin*

BEER.

PLATE I.

ION OF BREWERY.



) PHILADELPHIA.

es. I *Hot Liquor Backs.* J *Steel's Mashing Machines.* K *Mash Tuns.* L *Under Back.* M *Wort Coppers.* N *Cooler.*
ks. U *Cask Lowering Machine.* V *Cask Raising Machine.* W *Steam Boilers.* X *Steam Engine.*

machine with an iron frame revolving on trunnions, supported on legs. Motion is given to this frame by a chain and pulleys driven from a shaft above. Inside the frame is an iron cradle of a size to suit the cask to be washed. Into this the cask is placed and secured by a chain. This cradle has also trunnions which work in the iron frame first mentioned. On one trunnion is a wheel, which works into a worm fixed on the outside of the iron frame. On the end of the worm shaft is a counterpoise weight, shown in the lower part of the illustration. As the frame revolves, the weight of the counterpoise weight gives at each revolution one turn in the opposite direction to the cradle that carries the cask.

A good example of a modern brewery is shown in BEER, Plate I. It is a longitudinal section of a brewery erected in 1874 for Messrs. SEDGWICK of Watford, and designed by Messrs. HENRY PONTIFEX & SONS, of King's Cross, London, who also constructed the plant and machinery. In this brewery the wort is boiled by fire, and the liquor heated by steam. By aid of the following description the general arrangements will be readily understood:—

The liquor is raised from a well by one of the sets of pumps shown in the engine-room, and forced into the cold liquor tank at the top of the brewery. The malt is raised by a sack tackle into the malt store; thence it runs through a malt hopper into the malt rolls in the mill-room, and when crushed it is raised by an elevator to the upper part of the building, and delivered into either of the grist cases shown over the mash tuns. The cold liquor runs from the cold liquor tank into the hot liquor backs, where it is raised to the necessary temperature by steam coils. To each grist case is fitted a STEEL'S mashing machine, through which the grist and liquor are delivered into the mash tuns. Each mash tun is furnished with an internal machine fitted with COURON'S patent mashing rakes. The wort runs off to the copper underback, which has a steam coil in it to keep up the temperature of the wort, and thence runs into the wort coppers, where it is boiled. After the hops are strained from the wort in the hop backs, it is pumped by the other set of pumps in the engine-room into the cooler at the top of the building. From the cooler the wort runs to a set of LAWRENCE'S patent refrigerators, which stand on the mash-tun stage. By passing through this apparatus it becomes properly cooled, and flows into the fermenting tuns, which are furnished with skimming apparatus and attemperators. After fermentation, the beer is run into casks in the tun-room, where the fermentation or cleansing is completed. From the tun-room, the beer barrels are lowered to the cellar beneath by the cask-lowering machine, and when required to be sent out are raised by the cask-raising machine. Two steam boilers in the copper house supply the steam for driving the steam-engine, heating the liquor, washing casks, &c.

This brewery, with the two mash-tuns, is capable of mashing about 100 quarters of malt at each operation.

Having thus far given a general view of brewing, and the various causes which affect its success, a few words will now be added on the preparation of particular beverages, and first among these will be noticed—

PALE ALE.—Pale or East India ale is nothing more than beer made from worts extracted from the palest malt, and boiled with the palest and best hops. Every attention is given to the selection of these materials, in order to insure the pale colour peculiar to this ale. A great deal of East India pale ale is now used at home, but it differs from that exported, inasmuch as it is less bitter and more spirituous; in every other particular of manufacture and composition they are alike.

The only localities where this excellent beverage is produced in large quantities are Burton, London, Glasgow, and Leeds.

The peculiar excellence of these ales is their remarkable keeping quality, and their retention of that delicate flavour of the hops which is so often lost in ordinary brewing, notwithstanding the utmost efforts being made to secure it.

Success in brewing pale ale depends on the temperature of the fermentation being kept low, since this alone can preserve the beer from the simultaneous formation of acetic acid with the alcohol: 72° Fahr. (22°·2 C.) is the highest degree of heat that can be safely depended upon.

Brewing, it is well known, has been long carried on in Bavaria on these principles; but for a long time there was great objection to their adoption by the more extensive firms of this country, on account of the great length of time required for perfect attenuation. This difficulty, however, has at length been overcome, the fermentations being now finished in as short a time as by the old mode.

The modes of mashing, boiling, cooling, &c., pursued in different pale ale establishments are the same as those already explained, and therefore a recapitulation is unnecessary.

The only particular which requires to be noted, in addition to what has been already said, relates to the use of the hops, which are added in larger quantity than for the manufacture of the common ales.

ROBERTS states that the proportion of hops varies from 20 to 22 lbs. per quarter of malt; but, considering that the density of the worts is not so high as in many other instances, being about 1·055 specific gravity or upwards, the above proportion must in the majority of cases be very considerably more than the brewers of the present day employ. About 16 lbs. per quarter may be taken as the average allowance, though more or less within certain limits may be used—according to the special object of the brewer—in making a richer beverage, or inoculating the ale with a larger proportion of the bitter ingredient. Considerable care is exercised by the pale ale manufacturers in having the worts well boiled with the very best hops, so that all the valuable constituents of the flowers may be taken up in the gyle; hence it is not unfrequent among the Burton brewers to continue the boiling for a period of two hours and a half or three hours. The cooling and pitching heat of the gyle are the same as have been described; and the fermentation and subsequent cleaning have also been fully explained. As, however, the routine and materials employed affect the fermentation, it may be well to offer a few observations upon this subject.

In making pale ales the fermentation should be restricted within the range of 60° to 68° or 72° Fahr. (15°·5, 20°, to 22°·2 C.), according to the degree of heat at the pitching, and the state of the weather. From the beginning of the attenuation till about three-fourths of the sugar are converted into alcohol, nothing further is required than to observe that the heat is gradually progressing in proportion to the attenuation. After this greater vigilance must be observed in skimming off the yeast and checking the action of the ferment, so that the further decomposition of the remaining portion of the sugar may take place at a declining temperature, during which the cleansing can be thoroughly executed.

When this is finished, and the clarified liquor is racked off, it is customary to allow it to rest for eighteen or twenty hours, in order that it may become more clear. It is then run into the casks, barrels, or hogsheads, as the case may be, which, when filled up to the bung, are shived or bunged tightly, and conveyed to the stores or consumers.

It is of great importance that the ale should commence a slow progressive fermentation in the cask, to retain its sparkling and brisk qualities; and to insure this, so much saccharine matter must be left in the liquor as will, by its conversion into alcohol and carbonic acid, communicate and keep up the requisite briskness; otherwise, if all the sugar were fermented in the first instance, and nothing left to develop the carbonic acid afterwards, the beer would be characterized as flat; while, if it retained nitrogenous matters and were conveyed to hot climates, it would in a short time become acid and putrefy.

Much of the success of the pale ale manufacture depends upon the care that is taken in selecting the best materials for its composition. It must also be understood that the several operations through which the malt and hops have to pass, as described in the preceding pages, must be performed with great attention, so as to preserve the colour, taste, and other properties of the ale in their fulness and purity.

SCOTCH ALES.—These ales at one time possessed a peculiar sweetness not to be found in other kinds of beer. This (especially as regards the Alloa ales) was owing to the addition of Russian honey to the liquor, a practice which has now been abandoned for many years. It is customary with the Scotch brewers to distinguish the quality of their ales by the price; thus, there are three guinea, four guinea, six guinea, and so on to ten and twelve guinea ales, but the latter are rarely brewed. The routine of mashing is much the same in Scotland as that usually followed by English brewers. The principal points of difference will appear from the annexed particulars gleaned from one of the most extensive brewers in Scotland.

The density of the wort depends, of course, upon the quality of the ale to be produced. The following are the densities adapted to the different qualities, reckoning by ALLAN'S saccharometer:—

For 3	guinea ale	the density is about......	65°
“ 4	“	“	80°
“ 5	“	“	95°
“ 6	“	“	108°
“ 8	“	“	115°
“ 10	“	“	125°

In preparing the worts of four guinea ale, two barrels of water at 175° Fahr. (79°·4 C.) are generally taken per quarter of malt and mashed; this is then sparged over with two and a half barrels of water at 190° Fahr. (87°·7 C.). For the other qualities of ale the same amount of water is taken for the mash, but the quantity used in the sparging is less in proportion to the density which the product has to indicate; thus, for five guinea ale the sparging is made with two barrels, and with one and a half for six guinea ale, whilst the spargings are not added at all in preparing the richer ales. Properly speaking, only one wort is drawn in Scotland, but the lengths of sparging, as just shown, make up for the after worts of the English brewer.

The hopping and boiling of the worts likewise vary but little from the practice already pointed out:—

4 to 5 lbs.	of hops	per quarter	are used for 4	guinea ale.
5 “ 6	“	“	“ 5	“
6 “ 7	“	“	“ 6	“

and so on. The period of boiling is from one to one hour and a half with the better class of ales, but is prolonged to two hours or longer when the product is poor. The criterion in this, as well as in those instances already alluded to, is the breaking of the flocculent matter, which the attendant carefully watches, and tests occasionally by taking samples in a small vessel and observing if the flocks readily precipitate. The cooling is performed in the usual way. The pitching heat is about 57° Fahr. (13°·8 C.), though sometimes it is reduced to 56° or even 54° Fahr. (12°·2 and 13°·3 C.). The period of attenuation extends from eight to twelve days, according to the weather, during which the heat rises to about 70° Fahr. (21°·1 C.) or more, but never higher if possible than 72° Fahr. (22°·2 C.). The extent of the attenuation varies from half to two-thirds of the original gravity. The cleansing of Scotch ales differs in no important particular from the usual system. It may be stated, however, that in Scotland the attenuation is finished in the fermenting tun.

The practice of adding flavourings in the shape of berries, &c., is now entirely discontinued in Scotland, at least among the more respectable brewers.

PORTER.—Previous to the year 1730 the malt liquors principally drunk in London were ale, beer, and twopenny, and it was usual for the customers to call for half-and-half, that is, half ale and half beer; half ale and half twopenny; or half of beer and half of twopenny. In course of time it also became the practice to ask for a pint or tankard of "three threads," signifying a third of ale, of beer, and of twopenny; and thus the publican had the trouble of going to three casks to get the mixture required. To avoid this, a brewer conceived the idea of making a liquor which should unite the flavours of the three; he did so, and called it "entire," and as it was a hearty beverage, it was very suitable for porters and other workpeople: hence the name, "porter."

The manufacture of this beverage constitutes a large and profitable branch of the brewing business, especially in the metropolitan cities. London and Dublin porter stand foremost in point of quality.

Considerable disparity of working exists in the various porter breweries throughout the kingdom, which arises from many circumstances, such as the taste of the consumers, the nature of the climate, and such like. In theory, however, the work differs little from the course laid down for brewing ale. Such variations as do exist will be briefly pointed out.

As in the case of pale ale, the great difference in porter from common ale is in the materials worked upon. The grist employed by the porter brewer is composed of various species of malt, mixed together in different proportions.

The annexed table gives a view of some of these mixtures:—

TABLE OF PORTER GRISTS.

No.	Black.	Brown.	Amber.	Pale.	Total.
1	9	0	0	91	100
2	6	34	0	60	100
3	2	30	10	58	100
4	3	25	15	57	100
5	4	24	24	48	100
6	5	0	95	0	100

Of these, preference is given to the last two, as being the fittest for preparing a good porter; in the others, the excess of black and brown malt occasions too much carbonaceous and useless matter in them, from which the porter acquires a disagreeable taste, as if liquorice and similar compounds were mixed with it.

The malt, on being subjected to a high temperature during the drying, undergoes a decomposition, by which the farinaceous portions are deprived of their natural properties, and converted into a more or less charred mucilaginous substance, according to the degree of heat communicated.

In the amber malt, although some slight carbonization has taken place, yet it is not so powerful as to prevent the saccharification of any considerable portions of the starch, and therefore, while the wort prepared from this is much more coloured than it would be if obtained from pale malt, the sacrifice of valuable matter is not very great. As, however, the colour given to the mash is not so dark as the consumers require, a sufficient quantity of black or patent malt is employed to communicate this shade. The amount of the patent malt varies according to the skill of the manager, and the quality of the remaining portion of the grist.

As in the preparation of pale ales, so in porter breweries, strict attention must be paid to the qualities of the materials.

In preparing the worts a stiff mash is made, and after an hour's maceration a further portion of water at a high temperature is added, making a total of about 3 barrels of water per quarter of grist. The whole is mashed for a short time after the second addition, and then the tun is covered till the time of racking, which generally happens in an hour or an hour and a half's time. The worts are pumped into the copper, and boiled and hopped in the usual way. The quantity of hops varies with the quality of the porter to be produced, and according as it is, or is not, intended for exportation: in this the manufacturer must be left to the exercise of his discretion. Among the porter brewers the proportion extends from 6 to 16 or 20 lbs. per quarter. The usual period of boiling is an hour and a half; the grist is in the meantime being further exhausted by the addition of more water, so that a second wort may be ready by the time the contents of the copper are turned into the hop-back.

The hops used in the first boil, and which are not entirely deprived of their virtue, are in many establishments returned to the copper with the second wort, the whole retained at the temperature of ebullition for two hours, and then discharged to the hop-back, from which the gyle flows off, and is cooled down afterwards previous to fermentation.

Before proceeding further it may be well to make a short allusion to the temperatures at which the mashings are performed. In consequence of the malt being in a slight degree carbonized or decomposed, the tendency to set or form a coagulum is not so great as when pale malt is macerated in the water, and therefore the temperature of the liquor may be to some extent higher than if pale malt were operated upon. The reverse of this was for a long time supposed to be the case. Nevertheless, when the large proportion of pale or amber malt is used, the brewers content themselves with the application of water at 160° or 165° Fahr. (71°·1 to 73°·8 C.) for the first mash; and in the second, liquor of a temperature of 170° to 180° Fahr. (76°·6 to 82°·2 C.). These heats are subject to a variation of 5° Fahr. (2°·7 C.), or more, according to the judgment of the manager and the composition of the grist.

Porter gyle, after being cooled, has usually a specific gravity of 1·052 to 1·081, varying with the intended price of the beer.

The fermentation of porter gyle should be vigorously carried on, till the attenuation has advanced to about two-thirds the original gravity; this will take place, according to circumstances, in from two to four days, the temperature rising from 10° to 15° (5°·5 to 8°·3 C.). As soon as it is observed that the heat remains stationary, the preparation for racking off the beer to the rounds or "pontos" for the purpose of cleansing is entered upon. Here the barm is discharged and collected in a proper recipient, either by the use of such an apparatus as that at BASS or ALLSOPP'S, noted on a previous occasion, or by the ordinary method. As soon as the sensible fermentation has ended in the rounds, the beer is either pumped into large open receivers, where it deposits a considerable quantity of the "lies" or "grounds," or is sent to the store vats to be matured.

When the beer does not clarify spontaneously, isinglass is generally used as a fining agent.

The finings are (according to Ure) prepared as follows:—The isinglass is cut into slender shreds and put into a tub with as much vinegar or hard beer as will cover it (in Germany sour wine is used), in order that it may swell and dissolve. In proportion as the solution proceeds, more beer must be poured upon it; but it need not be so acidulous as the first, because, when once well softened by the vinegar, it readily dissolves. The mixture should be frequently agitated with a bundle of rods, till it acquires the consistence of thin treacle, when it must be equalized still more by passing through a tammy-cloth or sieve. It may now be made up with beer to the proper measure of dilution.

The quantity generally used is from a pint to a quart per barrel, more or less, according to the foulness of the beer. But before putting it into the butt, it should be diffused through a considerable volume of the beer with a whisk, till a frothy head be raised upon it. In this state it is poured into the cask and briskly stirred about, after which the cask should be bunged down for at least twenty-four hours, when the liquor should be limpid.

Sometimes the beer will not be improved by this treatment; but this should be ascertained beforehand by drawing off some of the beer into a cylindrical jar or phial, and adding to it a little of the finings. After shaking and setting down the glass, it is to be observed whether the feculencies begin to collect in flocky parcels, which slowly subside, or whether the isinglass falls to the bottom without making any impression upon the beer. The latter is always the case when the fermentation is incomplete, or a secondary decomposition has begun.

In Germany the finings are added to the worts prior to fermentation, as soon as they are let into the setting-back or tun, and immediately after adding the yeast to it. They are administered by mixing them in a small tub with twice their volume of worts, raising the mixture into froth with a birch whisk, and then stirring it into the worts. The clarification becomes manifest in a few hours, and when the fermentation is completed the beer is as brilliant as can be wished.

Porter intended for keeping, or for shipment to warm climates, requires to be as free as possible from any dregs or yeasty matter, and to be well seasoned. Nothing will avail the brewer in this particular so much as using the best materials.

Good porter has generally the following characteristics:—It is perfectly bright, dark-coloured, brisk or well impregnated with carbonic acid, light, sufficiently bitter to the taste, and free from too much acidity.

According to the opinion of several in the trade, the Excise regulations, as at present existing, depress their operations very much, in consequence of the duty being levied upon the malt, on the assumption that it will yield four barrels of beer of 19·4 lbs. per barrel, or specific gravity 1·054.

Laying down 84 lbs. as the maximum yield of a quarter of porter grist, this amount cannot be far from the truth, and according to many brewers the produce is more frequently 80 lbs. than otherwise; indeed, considering the loss in boiling, hopping, and fermenting, it is evident that the forementioned produce cannot be fully obtained. No drawback is allowed by the Excise upon the difference of the quantity upon which duty is levied, and that actually obtained; hence it is very evident that the manufacturer suffers.

BAVARIAN BEER.—The great and distinguishing feature of Bavarian beers (which are slowly fermented), is, that they do not contract any acidity when exposed to the air, whilst the products of English, Scotch, and French brewings invariably become sour under such circumstances. In addition to this very characteristic mark of the soundness of Bavarian beers, they possess in a high degree all the other qualities by which good beer is known, and hence are held in high estimation.

These valuable qualities are owing to the perfect system of fermentation to which the worts are subjected—a system which in itself has solved one of the most beautiful theories connected with it. Allusion has been already made to the causes of acidity in the gyle when speaking of boiling, but the explanation of the Bavarian method of fermentation will afford a clearer illustration of the matter than that adverted to. In gyles, generally speaking, the proportion of gluten, with reference to its utility in producing yeast or assisting in the fermentation, is greater than that of the sugar to its requirements in the formation of spirit and giving *fullness* to the drink; and although much of this excess may be removed by the boiling, still, after the usual process of attenuation has been effected, as by the generality of brewers in this country, a very considerable quantity of glutinous substance remains dissolved, and it is this that exposes the liquors to so much danger of spoiling, whereas, if it were removed, no apprehension of decomposition need be entertained. The process of fermentation, as carried out in Bavaria, is simply such as will entirely remove this excess of nitrogenous matter in the worts, and leave a beer containing no other constituents than water, alcohol, sugar, and the conserving principle of the hop.

The course adopted is the following, as described by Dr. Charles Graham:—

The Bavarian, or old Bavarian, method of decoction consists in boiling the worts along with the grains.

The malt, after it is properly ground, is thrown into cold water, and it is allowed, after being mashed, to remain in cold water for a period varying from one to three hours. After this process has gone on as long as the brewer may think necessary, hot water is added, in order to raise the temperature of the mash in the tun to about 95° to 100° Fahr.

(35° to 37°·7 C.). The infusion process is thus set up.

After standing a short time, the tap is opened, and grains, meal, water, and everything is run off, and that is pumped up into a boiler. The wort and grains, with the moderate quantity of water used, form together a thick mass, which the Germans call *dickmaisch*. This thick mass is then boiled vigorously for half an hour. After it has been boiled it is turned back again into the mash-tun, in order to raise the temperature to about 122° or 125° Fahr. (50° to 51°·6 C.). The infusion process then goes on again. After that a second thick mash is again pumped up into the boiler, and again boiled briskly for half an hour, and it is then again run into the mash-tun, and the temperature in this way is raised to 145° Fahr. (62°·7 C.). It is then allowed to stand quietly after a little mashing. Before the thick mash is run from the copper, the mash apparatus is set to work for about ten minutes previously. It is thus infused, and then, in the old Bavarian method, the third mash, or *lautermaisch*, is run off, that is to say, a tolerably clear one not mixed with grains. This is pumped into the copper and boiled. After it has boiled about half an hour it is run into the mash-tun, and the temperature raised to 165° or 170° Fahr. (73°·8 to 76°·6 C.).

Thus the temperature is first that of cold water, in the second stage it is raised up to about 100° Fahr. (37°·7 C.), in the third stage to about 140° Fahr. (60° C.), then in the fourth stage to from 165° to 167° Fahr. (73°·8 to 75° C.), and lastly, the process is allowed to go on for a period of one hour. In the old Bavarian method, after tapping, sparging was done with cold water. Of late years hot water has been used, in that particular imitating the Scotch or English method. There are modifications of this process. For instance, sometimes instead of running off in the third stage the *lautermaisch*, a third *dickmaisch* is run off, and no *lautermaisch* at all. In other cases, instead of two thick mashes, only one is used, having instead two thin mashes, and so on.

The points which are gained by this method of boiling the thick mash are the following. The activity of a large part of the diastase is destroyed so far as its converting energy is concerned; but there is still some left in the tun. Now diastase is able to convert about 2000 times its own weight, and the Bavarian brewer maintains that he leaves a sufficiency of diastase in his tun to carry on the process which he has in view.

The boiling process, while it destroys the diastase, which may be looked upon as a disadvantage, has, at any rate, this advantage, that it thoroughly breaks up the integuments of the malt, and in that way the starch is converted into a sort of starch-paste. When the wort is run back again into the mash-tun, it there meets with the diastase that has not been destroyed, and the starch-paste is then very rapidly converted into dextrine and sugar. In addition to that, it is generally maintained by Bavarian brewers that in this way a large amount of soluble albuminous matter is brought into their worts, and that this soluble matter has undergone in that way a process of cooking, and therefore their worts and beer are rounder. It is an undoubted fact, whether that be really the case or not, that while they are killing so much of their diastase, they naturally have a greater ratio of dextrine to the sugar, so that their worts are rich in dextrine and poor in sugar. When such worts are fermented less alcohol is produced, so that, finally, the difference may be summed up in this way, that the beer made from the worts mashed in this process are less alcoholic or stimulating, because they had originally less sugar, but that they are rounder or fuller in the mouth; and in addition it is supposed, on account of the long cooking the albuminous matter has undergone, that it tends to preserve the beer better.

The fermentation of the beer is carried out in the main upon what is called the "bottom fermentation" principle. The tuns are all placed underground, in order that the temperature may be kept equal, and in addition they are surrounded with large quantities of ice. Sometimes there is from 8000 to 10,000 tons of ice placed around the fermenting room. The object of this is to keep the temperature low, and it is always kept as low as 40° Fahr. (4°·4 C.). The Bavarian brewers are also particularly careful in their attention to the purity of air, and the air is removed from time to time with a view to get rid of the small spores that are given off from the yeast *torulæ*. They are no less careful to keep the walls thoroughly clean. The temperature at which the fermentation is set varies slightly, but not more than 3° Fahr. (1°·3 C.). The lowest is about 42°, and perhaps the highest 44° or 45° Fahr. (5°·5, 6°·6, and 7°·2 C.). Ales intended for quick consumption are sometimes pitched at about 48° Fahr. (8°·8 C.).

The "bottom" yeast which Bavarians employ is very much the same as the English "top" yeast; but the yeast-cell is slightly smaller, and as a rule is ovoid. The amount added depends on a number of circumstances, because the yeast varies in power. It generally varies from 7 or about 8 litres to 12 for every 4000 litres of wort used. It is applied, generally speaking, in the same manner as in this country, by simply mixing it with a little of the wort and then supplying that to the remainder. Another plan is to take a portion of the wort, add the yeast to it so as to start fermentation, and after it has gone on about twelve hours, adding it to the remaining wort. The object of doing this is that as little yeast as possible may be used.

The phenomena observed in a Bavarian fermenting tun (and their tuns are very much the same as those at Burton, simply a deep tun or barrel) are these:—After some twelve hours a little carbonic acid is formed. Of course that which is formed at first is absorbed, and as the temperature is very low, much more is absorbed than with us. In some twenty-four to thirty hours a scum appears, and then twelve to fifteen hours later there is thrown up to the surface a light yellow or brown yeast, containing the resinous matter of the hops, together with many of the dead cells. This is very carefully removed, for the purpose mainly of keeping the yeast pure. The fermentation goes on after this much more slowly and regularly, and the carbonic acid is given off in very minute bubbles; hence therefore the cells do not rise to the surface, but sink to the bottom.

The process goes on for some ten, twelve, fourteen, or sixteen days, and in the case of very strong ale, at a very low temperature, as long as three weeks. But as a rule it lasts some twelve days, and the attenuation at the end of that time is carried to about the extent of one-half the original gravity. Having completed the action in the fermenting tun, the gyle is run into a large store barrel, and here the sugar and dextrine of the wort are gradually used up by the yeast cells and converted into carbonic acid.

The sugar of course breaks up readily enough into carbonic acid and alcohol, but dextrine is a much more inert body, and in the absence of sugar is with difficulty broken up. But, though dextrine does not by itself yield readily to the alcoholic decomposition, yet in the presence of grape sugar it does break up gradually into alcohol and carbonic acid.

On each large barrel or fermenting tun (they are not very large) is fixed a manometer or pressure gauge. The barometer is also found in each brewery, and of course the thermometer, and the brewer every day as he passes along notices, not merely the atmospheric pressure, but also the internal pressure in the store vats; because by so doing, he is enabled to decide whether the slow decomposition of the sugar and the consequent introduction of alcohol is going on steadily. As he passes down he looks at each small gauge, and notices by the scale the amount of internal pressure, which should always be equal to some few inches of water; and if he finds that the pressure of the internal carbonic acid is much less than it ought to be, he then feeds the yeast in such a barrel with sugar.

Thus in the Bavarian system, where the ale is kept for weeks and months, there is a gradual process of feeding going on. The German brewer carefully avoids oxidation by a slow system of feeding, little by little, and in that way he insures that there shall always be a pressure inside greater than the atmospheric pressure. While he notices the indication of the manometer, he bears in mind the atmospheric pressure outside, because it may occasionally happen that the barometer has fallen or risen some 2 or 3 inches, and of course therefore he guides his process, not only by looking at the barrel manometer, but also at the external atmospheric pressure.

There are, perhaps, no brewers in the world more careful to avoid exposure to the action of the air than the Bavarian brewers. In their store vats they allow a space of about a hand-breadth between the surface of the liquid and the bung itself, with a manometer indicating the difference between the internal and external pressure. And they are equally careful in the original fermenting process to have a layer or covering of carbonic acid over the fermenting wort.

But a process of oxidation is nevertheless going on, and the oxygen is derived from the liquor. Water is decomposed by the yeast organisms, and the oxygen of the water goes to oxidize the albuminous matters, but at that low temperature does not oxidize any of the alcohol; consequently, in the Bavarian system, less aldehyde is formed, and less acetic acid, and owing to the low temperature, but a very small quantity of lactic acid and acetic acid. So long as the beer *torulæ* are working, there is a guarantee that at that low temperature the acetic acid ferment (the *Micodermi aceti*), shall not be able to thrive, and also that the lactic acid ferments shall not thrive, because the conditions are unfavourable for their rapid growth. On the other hand, a low temperature is very favourable to the production of the yeast *torulæ*, and so long as these are growing fast and multiplying, even if the others come into the field, they are gradually driven out, because the climatic conditions are unfavourable to their rapid development. Hence, in the Bavarian system, the sugar is thoroughly and economically decomposed, and at the low temperature employed the major portion of the oxygen derived from the decomposition of the water goes to oxidize the glutinous matter of the wort. The temperature of the fermenting tun is kept down by the Bavarian brewers, but not in the same way as in this country. The plan used is very simple; large lumps of ice are thrown into the fermenting tun, or when that is not available, because it turns into water and makes the beer too weak, a small floating vessel is nearly filled with ice, and placed in the middle of it.

The beer produced in this way contains very often no more than 1½ to 2 per cent. of alcohol. It has a full-mouthed round flavour; and though the amount of hop used is very slight, yet it has a delicate aroma. The peculiar flavour which the Bavarian ale has is not in any way to be attributed to fermenting at low temperature, but is produced entirely by the very free use of pitch or resinous matters to protect the wood of the fermenting tun. The result is, that as alcohol is formed it dissolves some of the resinous matters, and gives the beer the taste which is so unpleasant to Englishmen.

As regards the fermentation generally, the salient features from a chemical point of view are, first of all, that the decomposition depends upon two factors, namely, temperature and pressure, and as they vary so do the products vary. High temperature—the barometrical pressure being the same—produces a rapid decomposition of the sugar in the wort, more hydrogen is evolved, more aldehyde is formed, and more acetic acid; at the same time less nitrogen is evolved, and on account of the favourable thermal conditions, there is also more lactic acid. Low temperature on the other hand, if the barometric pressure be the same, produces a slower action; but there is less hydrogen, and more nitrogen, and there is a more complete oxidation of the albuminous matter. This is important, because on the perfect separation of the glutinous matter depends the future store-keeping qualities of the ales. High barometric pressure may be considered very much the same in its effects as low temperature, and *vice versâ;* but the range of variation of the barometer is never greater than some 3 inches, and consequently this is by no means so important a factor as the question of temperature. For store ales, fermentation ought to be carried on at a temperature intermediate at any rate between the Bavarian and the very high temperature that some of the British brewers use; and above all, the secondary fermentations should be carried out underground, under conditions of low and equable temperature, which ought not to be allowed to exceed 55° Fahr. (12°·7 C.).

Lambick Beer. *Faro beer; bière de mars.*—In this mode of brewing the wort is self-impregnated with the ferment. This process is practised to some extent in Dorsetshire. It is also carried out on a large scale in Belgium. The brewers mix barley malt with an unequal weight of unmalted wheat (wheat contains a large amount of gluten); the mashing is carried on by a modification of the Bavarian process, that is to say, they make a moderately cool mash, starting at a low initial temperature, and then by repeated boilings finally obtain a wort which, like the Bavarian wort, contains a large quantity of dextrine. The wort is then cooled, and is placed in a number of barrels, the bungholes of which are left open. The barrels being filled, the wort is left to mature.

Sometimes it is weeks before the fermentation appears, but sooner or later fermentation is started; occasionally, when it is very obstinate, they add a little unboiled wort to stimulate it, much in the same way that English brewers add a little malted barley for the purpose of stimulating sluggish fermentation. The fermentation goes on slowly for weeks or even months, and like the German system, it is generally of a bottom character; the bulk of the yeast falls to the bottom, though at the same time a portion is thrown out to the surface. After the fermentation has gone on for this long time, by degrees the beer becomes clear.

For Faro beer they boil their worts about six hours, and for Lambick, or *bière de mars*, they carry on the boiling process for twelve or fourteen hours. The ale thus produced is excessively hard, and contains a large quantity of lactic acid present, though when it has once cleared itself, the lactic acid seems to guard it against any future attack of these small organisms. When it is once made, and sometimes it takes from two to four years before the beer is fit to drink, it withstands any future oxidation remarkably well.

Adulteration of Beers.—This subject, fortunately, is not so difficult to deal with at the present day as it was about half a century ago. Whether this result is owing to the increased morality of the brewer, or to the vigorous measures taken by Government in detecting and punishing sophisticators, is a difficult point to determine; but certain it is, that the ingredients which are said to have been employed at that time are positively frightful to contemplate.

The cause of some of the adulteration might, with truth, be said to originate with the consumers, some fancying a pale liquor, whilst others preferred an amber or brown.

At one time the close approximation of the colour to black was imagined to be a sure sign of perfection.

To communicate such a shade, and at the same time evade the duty payable upon the malt, many resources were tried, such as the use of caramel or treacle boiled down to blackness, elder-berries, Spanish juice, &c., and these continued to be used for a considerable period. Caramel, or burnt sugar, and liquorice, are said to be employed at the present day. In the other departments of the manufacture, especially in the means employed for preventing acidity, raising of a creamy head, and giving a semblance of age to the product, many brewers have recourse to such substances as sulphate of iron, chalk, or the carbonates of alkaline earths.

When the beverage is made from good materials, and with proper care in the fermentation, it remains sufficiently viscid from the gummy matter and sugar in solution, so that in pouring it from one vessel to another it gathers on its surface a close creamy foam or head, which, when blown aside, readily closes again. This is more particularly the case with good porter; but when the body or unfermented matter of the beverage is in small or insufficient quantity this does not take place, and the bad quality of the liquor is thus detected by the consumer.

In order to conceal this inferiority and give an appearance of richness, the brewer sometimes, but the vendor very often, adds more or less of "heading stuff," made of isinglass and sour ale beaten well together, introducing a small quantity of this with an ounce or two of sulphate of iron into each hogshead. This has the effect of raising a froth upon the liquid, and also of making it to close immediately when blown aside.

By the use of chalk, beer which has become sour may be deprived of its acidity, but it will never be palatable after such treatment, especially if the quantity of acid in it is rather large.

When beer turns hard, especially in the porter establishments, the practice is to mix the sour with fresh-brewed beer, and send it to the consumers at once as old porter.

Many ingredients are said to be mixed with beer, particularly by retailers, to increase the stupefying properties of the liquor, and even the thirst of the consumer; but such adulterations have not come within the range of the Editor's experience. It is asserted, however, that many herbs and seeds, such as wormwood, India berry, or *cocculus indicus*, the fruit of the *Picrotoxia*, or *Menispermum cocculus* (a plant containing an active poisonous principle), *picrotoxin*, and various others, are employed to impart bitterness.

Analysis of Beer.—This is of much importance to the brewer and the public; to the first it is a means whereby he learns the composition of worts or gyle, and can modify his mode of working accordingly; to the second it is of great consequence, as it detects the often poisonous adulterations of malt liquor. It is of importance also to the exporter to be able to analyse his beer, and from the results to deduce the original gravity of the wort; for by Act 10th Victoria, cap. 5, a drawback is granted of five shillings per barrel of 36 gallons upon beer exported, of which the worts used before fermentation are of not less specific gravity than 1·054, and not greater than 1·081; and a drawback of seven shillings and sixpence upon beer exported, the worts of which, before fermentation, were not under 1·081 specific gravity.

The constituents most necessary for the analyst to determine are, the alcohol, water, acetic acid, saccharine, glutinous, and bitter extractive matter of the malt and hops. A complete investigation of these is sometimes necessary for the purpose of detecting any foreign or destructive principle introduced as an adulterant.

Much may be learned from an attentive examination of the beer before it is analysed. It should be perfectly clear; turbidness shows that either the acetic or vinous fermentation is going on. The smell and taste of the hops, and the quantity of carbonic acid, which may be judged of from the creaminess of the head (unless head matter has been employed), afford to the connoisseur a means of judging of the quality of the ale with tolerable certainty.

For excisable purposes, the following is the method recommended for the analysis of beers, so as to find the original density of the wort. An accurately graduated four ounce bottle is provided and filled with the beer to be examined, after which the contents, together with the rinsings, are transferred to a retort to which a condenser is affixed, and the measured bottle is used as a receiver. Distillation is then continued till somewhat more than half the quantity of liquid is drawn over, so as to insure the elimination of the whole spirit. The remainder of the measured bottle is then filled with distilled water, and the specific gravity of the mixture taken at 60° Fahr. (15°·5 C.). If, instead of 1·000, the weight should indicate ·987, it shows that the weight of the diluted spirit is 13° less than the water; this is *the spirit indication of the beer.*

By referring to the tables drawn up for this purpose (see ALCOHOL), the density of the worts producing it will be ascertained. In this case it is 59·4. The residue in the retort must then be washed with a small quantity of distilled water into the four ounce bottle, which is then filled with water, and the gravity found as before, and its excess over that of water added to the preceding number, plus 1000, and the sum will be the original gravity of the wort. Thus—

If the spirit gravity be................	59·4
And the extract do.....................	1030·0
Gravity of the worts,...............	1089·4

The annexed table, constructed by Professors GRAHAM, HOFMANN, and REDWOOD, is that by which the Excise are guided in most cases of this description. These numbers in the body of the table indicate the strength of wort corresponding to the spirit indication in the margin.

Degrees of spirit indication	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
0	0·0	0·3	0·6	0·9	1·2	1·5	1·8	2·1	2·4	2·7
1	3·0	3·3	3·7	4·1	4·4	4·8	5·1	5·5	5·9	6·2
2	6·6	7·0	7·4	7·8	8·2	8·6	9·0	9·4	9·8	10·2
3	10·7	11·1	11·5	12·0	12·4	12·9	13·3	13·8	14·2	14·7
4	15·1	15·5	16·0	16·4	16·8	17·3	17·7	18·2	18·6	19·1
5	19·5	19·9	20·4	20·9	21·3	21·8	22·2	22·7	23·1	23·6
6	24·1	24·6	25·0	25·5	26·0	26·4	26·9	27·4	27·8	28·3
7	28·8	29·2	29·7	30·2	30·7	31·2	31·7	32·2	32·7	33·2
8	33·7	34·3	34·8	35·4	35·9	36·5	37·0	37·5	38·0	38·6
9	39·1	39·7	40·2	40·7	41·2	41·7	42·2	42·7	43·2	43·7
10	44·2	44·7	45·1	45·6	46·0	46·5	47·0	47·5	48·0	48·5
11	49·0	49·6	50·1	50·6	51·2	51·7	52·2	52·7	53·3	53·8
12	54·3	54·9	55·4	55·9	56·4	56·9	57·4	57·9	58·4	59·9
13	59·4	60·0	60·5	61·1	61·6	62·2	62·7	63·3	63·8	64·3
14	64·8	65·4	65·9	66·5	67·1	67·6	68·2	68·7	69·3	69·9
15	70·5									

WATTS gives the following method for ascertaining the amount of alcohol ("Dict. of Chemistry," vol. i. p. 530):—15 to 30 ounces (500 to 1000 grammes) are distilled in a somewhat capacious retort, having its neck inclined upwards and connected with a Liebig's condenser; the distillate is received in a tared flask, weighed, and its specific gravity determined at 60° Fahr. (15°·5 C.), that of water being assumed = 1·000; or the proportion of alcohol may be found by testing the distillate with a delicate alcoholometer. The weight per cent. of alcohol is thus found by means of Table A, and hence the total amount of alcohol in the given quantity of beer may be found.

Suppose, for instance, 1000 grammes of beer gave 615·38 grms. of distillate of specific gravity 0·98949 at 60° Fahr., then, according to the tables, the distillate would contain 37·6 grms. alcohol. Now these 37·6 grms. of alcohol were obtained from 1000 grms. of beer, consequently the amount of alcohol in the beer is 3·76 per cent. The trouble of calculation may be saved by diluting the distillate till its weight becomes equal to that of the beer employed; the specific gravity will then at once give the percentage by weight of alcohol in the beer. If, for example, the distillate after dilution exhibited a specific gravity = 0·9932, the percentage of alcohol would be 3·76. If a TRALLES alcoholometer were used it would show in the distillate, before dilution, a percentage by volume of 7·6, corresponding to 6·11 by weight. In using the alcoholometer it is best not to dilute the distillate, unless the instrument is specially graduated for very weak liquids. If the observed specific gravity, or alcoholometer degree, does not occur in the table, the weight per cent. of alcohol will be found by interpolation.

The residue in the retort may be used for determining the amount of extractive matter in the beer. For this purpose it is diluted with water, after cooling, till its weight becomes equal to that of the beer before distillation; and the amount of extractive matter is then found from its specific gravity by means of Table B.

A table by Dr. URE of the specific gravity of pure syrup, which does not differ very greatly from that of malt extract, is given at page 299.

TABLE A. SPECIFIC GRAVITY AND STRENGTH OF SPIRITS.

Volume per cent.	Weight per cent.	Specific Gravity.	Volume per cent.	Weight per cent.	Specific Gravity.
1·0	0·80	0·99850	4·6	3·68	0·99336
1·1	0·88	0·99835	4·7	3·76	0·99322
1·2	0·96	0·99820	4·8	3·84	0·99308
1·3	1·04	0·99805	4·9	3·92	0·99294
1·4	1·12	0·99790	5·0	4·00	0·99280
1·5	1·20	0·99775	5·1	4·08	0·99267
1·6	1·28	0·99760	5·2	4·16	0·99254
1·7	1·36	0·99745	5·3	4·24	0·99241
1·8	1·44	0·99730	5·4	4·32	0·99228
1·9	1·52	0·99715	5·5	4·40	0·99215
2·0	1·60	0·99700	5·6	4·48	0·99202
2·1	1·68	0·99686	5·7	4·56	0·99189
2·2	1·76	0·99672	5·8	4·64	0·99176
2·3	1·84	0·99658	5·9	4·72	0·99163
2·4	1·92	0·99644	6·0	4·81	0·99150
2·5	2·00	0·99630	6·1	4·89	0·99137
2·6	2·08	0·99616	6·2	4·97	0·99124
2·7	2·16	0·99602	6·3	5·05	0·99111
2·8	2·24	0·99588	6·4	5·13	0·99098
2·9	2·32	0·99574	6·5	5·21	0·99085
3·0	2·40	0·99560	6·6	5·30	0·99072
3·1	2·48	0·99546	6·7	5·38	0·99059
3·2	2·56	0·99532	6·8	5·46	0·99046
3·3	2·64	0·99518	6·9	5·54	0·99033
3·4	2·72	0·99504	7·0	5·62	0·99020
3·5	2·80	0·99490	7·1	5·70	0·99008
3·6	2·88	0·99476	7·2	5·78	0·98996
3·7	2·96	0·99462	7·3	5·86	0·98984
3·8	3·04	0·99148	7·4	5·94	0·98972
3·9	3·12	0·99434	7·5	6·02	0·98960
4·0	3·20	0·99420	7·6	6·11	0·98949
4·1	3·28	0·99406	7·7	6·19	0·98936
4·2	3·36	0·99392	7·8	6·27	0·98924
4·3	3·44	0·99378	7·9	6·35	0·98912
4·4	3·52	0·99364	8·0	6·43	0·98900
4·5	3·60	0·99350			

TABLE B. SPECIFIC GRAVITY AND STRENGH OF MALT EXTRACT.

Specific Gravity.	Malt Extract in 100 parts of Liquid.	Specific Gravity.	Malt Extract in 100 parts of Liquid.
1·000	0·000	1·036	8·925
1·001	0·250	1·037	9·170
1·002	0·500	1·038	9·413
1·003	0·750	1·039	9·657
1·004	1·000	1·040	9·901
1·005	1·250	1·041	10·142
1·006	1·500	1·042	10·381
1·007	1·750	1·043	10·619
1·008	2·000	1·044	10·857
1·009	2·250	1·045	11·095
1·010	2·500	1·046	11·333
1·011	2·750	1·047	11·595
1·012	3·000	1·048	11·809
1·013	3·250	1·049	12·047
1·014	3·500	1·050	12·285
1·015	3·750	1·051	12·523
1·016	4·000	1·052	12·761
1·017	4·250	1·053	13·000
1·018	4·500	1·054	13·238
1·019	4·750	1·055	13·476
1·020	5·000	1·056	13·714
1·021	5·250	1·057	13·952
1·022	5·500	1·058	14·190
1·023	5·750	1·059	14·428
1·024	6·000	1·060	14·666
1·025	6·244	1·061	14·904
1·026	6·488	1·062	15·139
1·027	6·731	1·063	15·371
1·028	6·975	1·064	15·604
1·029	7·219	1·065	15·837
1·030	7·463	1·066	16·070
1·031	7·706	1·067	16·302
1·032	7·950	1·068	16·534
1·033	8·195	1·069	16·767
1·034	8·438	1·070	17·000
1·035	8·681		

The amount of alcohol in beer may in most cases be calculated with sufficient accuracy for practical purposes, from the difference in the specific gravity of the boiled and unboiled beer, according to the following principle:—The specific gravity of the unboiled beer is less than that of the boiled beer, in the same proportion as the specific gravity of spirit of wine of equal alcoholic strength is less than that of water.

To determine the amount of alcohol in beer accordingly, the beer is first freed from carbonic acid by brisk agitation in a capacious flask, assisted perhaps by very gentle heating, and its specific gravity accurately determined. It is then boiled to drive off the alcohol, and the residue is diluted with water, till its weight becomes exactly equal to the original weight of the beer; it is next filtered, if necessary, through a covered filter, and its specific gravity likewise determined. The amount of alcohol is then calculated, as in the following example:—

Suppose the specific gravity of the unboiled beer free from carbonic acid to be 1·0280, and after boiling and dilution with water, to be increased to 1·0320: then, according to the principle just stated, the specific gravity of pure spirit of the same alcoholic strength as the beer, will be to that of water as 1·0320 : 1·0250; that is to say, it will be $\frac{1{\cdot}0250}{1{\cdot}0320} = 0{\cdot}9932$, which, according to Table A, corresponds to 3·76 per cent.

The empirical rule for finding the specific gravity of spirit of equal strength with the beer is:—Divide the specific gravity of the unboiled beer by that of the boiled beer, after its original weight has been restored by dilution.

It is clear that the results obtained by this method (called in Germany the "Specific Beer-test"), will be more exact in proportion as the composition of the beer differs less from that of pure spirit of equal strength; in other words, the smaller the amount of the extractive matter contained in the beer.

The quantity of extractive matter in beer may be determined by evaporating a known quantity of beer in a platinum or porcelain dish, and drying the residue in an air bath at 212° to 239° Fahr. (100°-115° C.), till it loses weight. Before weighing it must be cooled under a bell jar, over chloride of calcium, as it is very hygroscopic.

It is seldom necessary to examine the extractive matter any further. It consists mainly of sugar, dextrin, albuminous matter, and lupulin (the bitter principle of the hop.)

The amount of dextrin and sugar may be determined by moistening the dried residue with water to a thin syrup, and gradually adding strong alcohol as long as dextrin is thereby separated. The clear sugar solution may then be decanted, and the dextrin freed from the remaining sugar by repeated solution in water and precipitation by alcohol. The solution of dextrin and sugar may then be evaporated to dryness and the residue weighed. The albuminous matter may be estimated from a separate portion of the beer by boiling it so as to coagulate the albumen, collecting the precipitate in a tared filter, then washing, drying, and weighing it. Lastly, the sum of the weights of the dextrin, sugar, and albuminous matter, deducted from the total weight of the extract, gives the quantity of lupulin.

Another simple process is as follows:—The beer is well agitated to free it from the carbonic acid which it contains, and then a certain weight is taken and introduced into a retort connected with a condenser and receiver, and the whole of the spirituous liquor drawn off and tested. (See ALCOHOL.) The residuary matter remaining in the retort, after the most part of the fluid has been distilled off as just stated, is to be mixed with as much distilled water as will make up the same bulk of liquid as was originally employed, and the specific gravity of this liquid is to be taken by an accurate hydrometer. By this means the quantity of alcohol and extractive matter in the beer is found. To determine the amount of sugar in the solid matter of the beer, a portion of the liquor is weighed and introduced into a flask or beaker, and boiled; if a coagulum should form, it is to be collected upon a dry tared filter, then washed, dried, and weighed. The liquor is next evaporated till it becomes thick; strong spirit of wine or concentrated alcohol is then added, causing a precipitate of the gum and mucilaginous matter, which is collected and washed with spirit till all the sugar is extracted; it is finally dried and weighed, and its quantity noted. By evaporating the alcoholic filtrate to remove the spirit, dissolving the residue in water, and boiling the liquid with a grape sugar test solution, made by dissolving—

100 grains of crystallized sulphate of copper,
200 grains of bitartrate of potassa,
800 grains of crystallized carbonate of soda,

in 8750 grains, or one pint of boiling distilled water, and filtering if necessary, a precipitate of suboxide of copper falls, which, when collected, dried, and weighed, affords an indirect but accurate method for ascertaining the amount of saccharine matter, since every 3 grains of the suboxide indicate 1 of grape sugar. Having thus ascertained the percentage of albumen, if any, as also of gum and sugar, then, by deducting their total from the quantity of fixed residue, the difference will be the percentage of lupulin, or extractive matter of the hop.

If the beer was adulterated with any of the bitter substances before mentioned, they will remain in company with the lupulin.

The quantity of acetic and lactic acid in beer is determined by weighing or measuring a certain portion, and neutralizing it with a standard solution of pure carbonate of soda or of ammonia, added gradually from a burette, and calculating the percentage of those acids from the quantity of the test liquor employed. If lactic acid be suspected, another weighed portion of the liquid should be evaporated to dryness, the residue affused with water, and neutralized by the forementioned solution. From the number of measures required, the quantity of lactic acid is calculated. The equivalent of dry lactic acid is 90. By deducting the amount of lactic from the total weight of acid, as above ascertained, the remainder will be acetic acid.

Carbonic acid gas may be determined either by boiling a quantity, say a quart of the beer, and collecting the gas in a pneumatic apparatus, or if this be not convenient, transmitting it into a solution of baryta or lime, and collecting, drying, and weighing the precipitate which it occasions. If lime-water be employed, every 50 parts of the precipitate will denote 22 of carbonic acid.

If inorganic adulterations be suspected, their presence may be proved by evaporating the beer to dryness, and incinerating the residue in a platinum capsule or basin, till the whole of the organic matter is dispelled, then dissolving the ash or fixed matter in hydrochloric acid, and testing—for iron, with sulphocyanide of potassium, which will give a blood-red coloration if it be present; for lime, by the addition of ammonia and oxalate of ammonia, which will cause a white precipitate. Common salt is almost always present; it may be estimated by dissolving a portion of the residue, after incineration, in water, filtering, and adding nitric acid and nitrate of silver to the liquid; from the weight of the precipitated chloride of silver the amount of salt is calculated. Should alum be present, it will precipitate in the form of white flocculi, on adding ammonia to the solution when testing for lime.

If copperas (ferrous sulphate) has been added to promote the heading, the liquid will give the reaction of sulphuric acid with chloride of barium, and the ash will contain an abnormal amount of oxide of iron.

J. L. LASSAIGNE, during his researches upon picric acid, discovered a distinctive difference between the bitter principle of the hop and this acid. He says that some time back this acid was used as a partial substitute for hops, and that the practice was carried on to a considerable extent in certain districts in France. With the view of finding a ready means for detecting this adulterant in beers, he undertook the investigation. He observed that the taste cannot distinguish between the bitterness of picric acid and the lupulin of the hop; but that, by having recourse to the following experiments, the presence or absence of the adulterant may be readily ascertained. The beer is to be agitated with a solution of subacetate of lead in excess; this throws down a precipitate, consisting of the bitter and most of the colouring matter of the hop, whilst picric acid, if present, is unaffected by this reagent, and therefore remains, communicating its peculiar taste to the liquid. Another test, LASSAIGNE remarks, is this, that common bone charcoal, purified by acids, will precipitate and retain the colouring matter of the beer; but that picric acid passes through this medium, communicating its natural canary yellow tint to the filtrate. Upon these applications he bases the method of recognizing very minute traces of the acid when added to beer.

In his experiments to prove the efficacy of the test, he operated upon equal portions of a well-made beer, to one part of which one-twelve or one-eighteen thousandth of the adulterant was added. On pouring into these samples subacetate of lead in excess, or on shaking them with powdered animal charcoal, the pure beer is almost entirely decolorized, whilst the adulterated sample retains its yellow citron colour. Exceedingly minute traces of the adulteration may be detected by evaporating the liquid, and when reduced to a half or quarter of its bulk, applying the tests.

According to **Pohl** the most delicate test for picric acid is its behaviour towards unbleached wool. A flock of sheep's wool, or any fabric made thereof, is immersed in the beer to be examined, and the whole boiled for ten minutes, it is then removed and thoroughly washed to remove the wort. If the beer is free from picric acid the wool remains white, but if only so much as one part of picric acid in 125,000 parts of beer is present, the wool becomes of a canary yellow colour, which is more or less strong according to the quantity.

It has been observed by **Brunner** that the dyeing of the wool is rendered easier and more certain by the application of a moderate heat (that of the water bath), and by previously acidulating the beer with hydrochloric acid. It must be observed, however, that besides the picric acid which stains the wool deep yellow, other colouring matters are thereby separated from the beer, which gives to the whole a dingy brown yellow colour. The presence of picric acid may, however, be detected with certainty by warming the wool with aqueous ammonia, filtering, concentrating to a small bulk on the water bath, and adding a few drops of solution of potassium cyanide. If the smallest trace of picric acid be present a red coloration will then be produced, due to the formation of potassium isopurpurate.

$$\overset{\text{Picric Acid.}}{C_6H_3(NO_2)_3O} + \overset{\text{Cyanogen.}}{3HCN} + \overset{\text{Water.}}{H_2O} = \overset{\text{Carburic Acid.}}{CO_2} + \overset{\text{Ammonia.}}{NH_3} + \overset{\text{Isopurpuric Acid.}}{C_8H_5N_5O_6}$$

By this method one milligram (0·154 grain) of picric acid may be detected in a pint of beer.

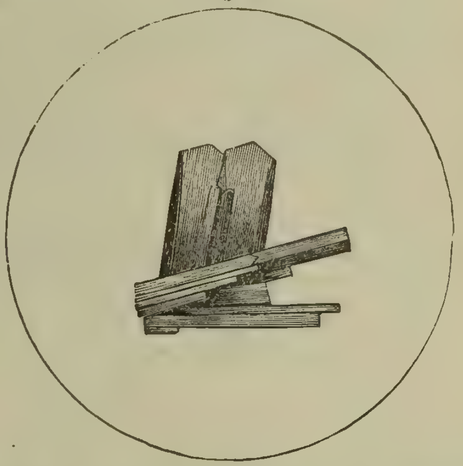
T. J. **Herapath** gives an accurate and rapid method for the detection of the active principle of *cocculus indicus* (*picrotoxin*) in beers. It is based upon the property which charcoal possesses of separating picrotoxin from its aqueous solution. An excess of acetate of lead is added to the beer under examination, in order to throw down the humulin and other extractive matters; the precipitate is removed by filtration; and the excess of lead in the filtrate abstracted, by transmitting a current of sulphuretted hydrogen gas through it, when it will fall down as sulphide of lead. To expel the free sulphuretted hydrogen after the filtration of the precipitate, the solution is boiled for some time, then slowly evaporated, until the residue assumes a thick consistency; a small quantity of pure animal charcoal is then agitated with it for a few minutes.

When the whole cools, the solution is filtered, and the charcoal, containing the picrotoxin, washed with the smallest possible quantity of water, then dried at 212° Fahr. (100° C.). After all the moisture is expelled, the charcoal is next boiled with some pure alcohol to dissolve the alkaloid accompanying it, the solution is filtered and evaporated, and the picrotoxin permitted to crystallize spontaneously.

If the adulterant be present in large quantities, it is deposited in the well-formed prisms—Fig. 35—or when the solution is rapidly concentrated, and speedily cooled, the crystals have a beautiful foliated or feathery appearance, similar to Fig. 36.

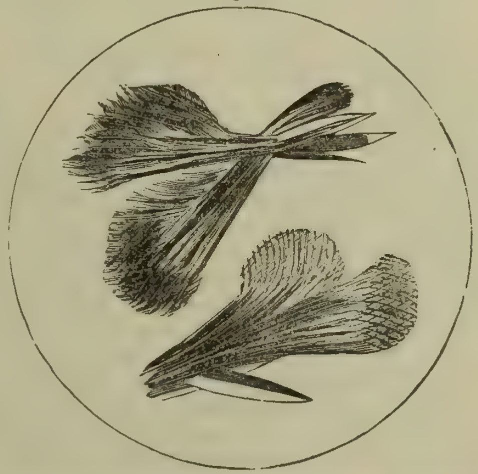
A small amount of this ingredient assumes the form of long radiating needles, which if the crystallization be conducted between two slips of glass, exhibit a peculiar tendency to place themselves nearly parallel with the edges of the upper glass. See Fig. 37.

Fig. 35.



It is said that by this means the alkaloid can be detected in the beer, when only half an ounce of the extract of picrotoxin has been added to the barrel.

Fig. 36.



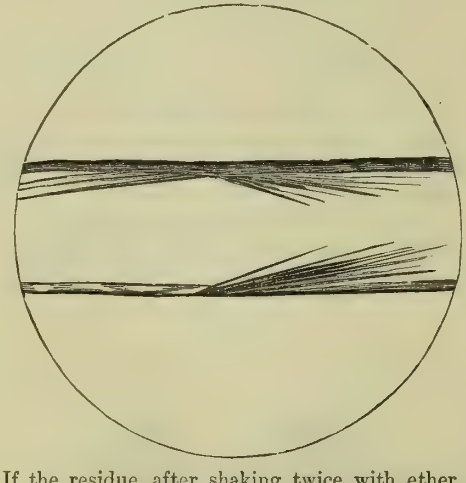
Blas, in his process, removes the hop bitters by shaking up 6 litres of the beer (previously evaporated to a small bulk and after saturation with soda) with one-tenth of its volume of ether; the residue is then acidified, and on again shaking with ether, the picrotoxin goes into solution, and is obtained as an intensely bitter mass on evaporating off the ether. This mass is dried in a water bath, taken up with alcohol acidified with one drop of acetic acid, and the filtered solution evaporated on a watch glass: if no distinct crystals are obtained, alcohol is added and recrystallization resorted to.

Picrotoxin crystals can be identified by their appearance (Figs. 35, 36, 37), their easy solubility in alcohol, bitterness, and the action of their solution on fishes.

Two fishes of about half an ounce weight are to be placed in 2 litres of water, and a portion of a solution of the crystals obtained as above is then added (this solution is made by dissolving the supposed picrotoxin in alcohol, adding water and boiling to drive off the alcohol); if it be really picrotoxin, the fish soon turn on their backs and die. Lupulin has not this poisonous action on fish. From 1 to 2 grammes of hops may be boiled in water and poured into the jar containing the fish without affecting them.

Two grammes of *cocculus indicus*, corresponding to 0·1 gram. of picrotoxin, is sufficient to kill a fish of a quarter to half an ounce in weight in ten hours.

Fig. 37.



If the residue, after shaking twice with ether as above, has a bitter taste, this points to the presence of salicin, quassin, and menyanthin. The liquid must then be precipitated with lead acetate; the filtrate freed from excess of lead, and mixed with tannic acid; the resulting precipitate warmed with alcohol and hydrated lead oxide; and the filtrate specially tested.

BLAS' process is varied thus, by DEPAIRE:—

The beer is shaken with common salt (360 grammes to the litre) and filtered; the filtrate shaken twice with ether; the residue from evaporation of the ethereal solution dissolved in alcohol; 15 c.c. of water and one drop of sulphuric acid added to the solution; the liquid heated for fifteen minutes in the water bath, cooled, filtered, and shaken with ether; the ethereal solution evaporated; and any crystals thus obtained recrystallized from alcohol and examined as above directed.

HOFFSTEDT'S process for the detection of spurious bitters in beer is thus translated in URE'S "Dict. of Arts," &c., vol. i. p. 332. It is applicable to the detection of picrotoxin, absinthin, menyanthin, quassin, and colocynthin.

The bitter principles likely to occur in beer may be divided into two classes: those which are precipitated by acetate of lead, and those which are not so thrown down.

1. Precipitable by acetate of lead:—

Lupulin.—It is not precipitable by tannin. It is soluble in alcohol and ether, but not in water.

2. Not precipitated by acetate of lead.

With tannin, after removal of lead by means of sulphuretted hydrogen.

a. Not precipitated by tannin:—

Picrotoxin.—Soluble in water, alcohol, and ether.

Absinthin.—Soluble in alcohol and ether, not in water.

b. Precipitated by tannin:—

Menyanthin.—Sparingly soluble in ether and cold water; easily in hot water. Turns brown and then violet with strong sulphuric acid.

Quassin.—Sparingly soluble in ether; soluble in 222 parts of cold water; not coloured by sulphuric acid.

Colocynthin.—Insoluble in ether; soluble in cold water. Turns first red and then brown with strong sulphuric acid.

The quantities needful for examination are 6 litres of bitter or Bavarian beer, or 4 of porter. This may seem excessive, but it must be remembered that a very small quantity of the above-mentioned drugs will impart a strong bitter taste to a large volume of liquid; and again, that the hop is never entirely omitted, since its peculiar efficacy in preventing spurious or secondary fermentation appears to be possessed by no other bitter.

The beer in question is to be evaporated down, first over the naked fire, and afterwards in the water-bath. Great care must be taken that it does not dry or burn on the sides of the vessel, or bitter principles may be generated and mask the reactions to be sought for. The thick mass is well treated with alcohol in a tall beaker. At the bottom will be found a thick gummy mass, and a somewhat turbid stratum of liquid over it. This is set aside to become clear; it is then poured off and the alcohol distilled off; the residue is concentrated to a syrup, and dissolved in alcohol. The solution is mixed with ten times its bulk of ether, which precipitates sugar; when clear, the liquid is decanted from the sediment and distilled. The residue is dissolved in warm water, and a portion of it tested with tannin. A pure well-hopped beer never gives a clear aqueous solution; a beer containing a little of the hop may; if the solution does not clear up, add a trace of alcohol. Besides lupulin, absinthin is insoluble in water. Filter off the resinous matter which may have been deposited, then precipitate the warm filtrate with acetate of lead, which must not be too acid; lupulin is then thrown down. Excess of lead must be carefully avoided, or menyanthin may fall down also; allow it to settle, filter, and wash the precipitate with hot water.

Filtrate.—Treat with sulphuretted hydrogen till all the lead is precipitated; filter and wash, first with warm water, and then with alcohol; remove sulphuretted hydrogen and free acetic acid by evaporation almost to dryness. If the residue is free from bitterness, no adulteration is present; absinthin never gives a clear aqueous solution, and menyanthin never a clear cold one. A turbid solution may contain all the spurious bitters; add a little alcohol till the solution becomes clear, and then tannin.

1. The precipitate formed is dried along with the hydrated oxide of lead suspended in water, and extracted with boiling spirit. In the residue of this extract colocynthin, menyanthin, and quassin, are separated by means of their behaviour with ether and water.

2. The precipitate is freed from tannin by means of acetate of lead, the precipitate filtered off, the lead removed by means of sulphuretted hydrogen, and evaporated. Picrotoxin separates out in crystals; absinthin remains as a yellow mass.

Levin Ender recommends the following mode of proceeding:—

1. Precipitate with acetate of lead.

Lupulin.—It gives no mirror with ammoniacal solution of silver.

2. Not precipitated by acetate of lead, but by tannin.

a. Soluble in ether. *Absinthin* gives a mirror with the silver solution.

b. Sparingly soluble in ether. *Menyanthin*, *Quassin.* The former gives a mirror, the latter not.

Picrotoxin, absinthin, menyanthin, edocynthin, reduce solution of silver; lupulin and quassia do not.

A. Dragendorff has recently made experiments on the bitter constituents of quassia, *Ledum palustre*, absinthe, *Menyanthes trifoliata*, *Cnicus benedictus*, *Erythræa centaureum*, gentian, willow bark, aloes, picric acid, colocynth, *cocculus indicus*, colchicum seeds, *Daphne mezereum*, *Capsicum annuum*, *belladonna*, *hyoscyamus*, *nux vomica*, and juniper berries.

He gives the following general methods of detection:—

1. 600 to 1000 c.c. of beer are evaporated to a syrupy consistence in the water bath, and then treated with 3 to 4 volumes of alcohol as free as possible from fusel oil, and the mixture allowed to stand for twenty-four hours. The whole is then filtered; the alcohol is distilled off from the filtrate, and the residual liquid is again filtered after standing from twelve to twenty hours in the cold. A few drops of dilute sulphuric acid are then added, and the whole is agitated with petroleum ether; the supernatant petroleum layer is washed with water, filtered through dry filter paper to remove the last traces of water, and evaporated to dryness on several watch glasses by spontaneous evaporation. The aqueous acid liquor is then agitated with benzene and with chloroform, and then again with benzene after addition of ammonia, to liberate alkaloids. Salicin from willow bark is extracted by agitating the aqueous liquor with amylic alcohol.

2. 600 to 1000 c.c. are heated till most of the dissolved carbonic acid is driven off; after cooling, basic lead acetate is added till no further precipitate is formed, after standing for some hours the whole is filtered; diluted sulphuric acid is then added to throw down the excess of lead; if the filtrate has a harsh or bitter taste the beer is suspicious; the whole is then evaporated in the water bath (after neutralization by ammonia) as quickly as possible, until only 180 to 200 c.c. are left, and then treated with benzene, petroleum ether, and chloroform, as in method 1.

Normal beer, examined by method 1, should give the following results. The petroleum ether extract contains:—

1. An amorphous, slightly bitter substance, soluble in ether and alcohol, and partially soluble in water.

2. A substance which precipitates basic lead acetate.

3. A substance which becomes red with Fröhde's reagent.

4. A substance which becomes red with sulphuric acid and sugar.

The benzene extract contains the same substances, and is more bitter; in addition it contains—

5. A body which becomes dark brown on treatment with sulphuric acid.

6. A substance which precipitates tannin.

The chloroform extract contains substances 1, 2, 5, and 6, in some instances in large proportions; also,

7. Pieces of a body precipitable by potassium iodide and phosphomolybdic acid.

8. A body which reduces ammoniacal silver nitrate.

9. A body crystallizable from ether, and with difficulty soluble in alcohol.

Of these substances, 2, 3, and 6 come from the hops; 1 from hops and malt together; 4, 5, 7, and 8 from malt; and 9 is formed from malt in fermentation.

The characters of the extracts obtained by the aid of the several solvents from the plant and vegetable products above mentioned having been carefully examined, and the reactions of the bitter ingredients thus isolated observed when treated with tannin, chloride of gold, basic lead acetate, ammoniacal silver solution, concentrated sulphuric acid, Fröhde's reagent, sulphuric acid and sugar, sulphuric acid with five equivalents of water ($H_2SO_4 + 5H_2O$), caustic potash solution, ferric chloride, Dragendorff constructed the following scheme, by which he states that, 600 c.c. of beer being taken for examination, 0·0005 gram. of atropine (= 0·06 gram. of belladonna leaves), 0·005 gram. of hyoscyamine (= 0·25 gram. of henbane), 0·0003 of strychnine, and 0·0005 gram. of brucine (= 0·03 gram. of nux vomica), can be detected.

Extract from Acid Liquor.

I. *Residue from Petroleum*—

a. Amorphous, first becomes brown, then violet, and soon red-violet, with sulphuric acid, *Traces of Absinthin.*

b. Amorphous, colourless, sharp-tasting, and rubefacient; coloured brown-red with sulphuric acid, *Traces of Capsicin.*

c. Amorphous, green, becomes red with sulphuric acid and sugar; no precipitate with ammoniacal silver solution, *Juniper berry resin.*

d. Crystalline, yellow, becomes blood-red with potassium cyanide, *Picric acid.*

Residue from Benzene—

A. Crystalline, not bitter; becomes purple-red with potash, and red becoming orange with sulphuric acid, *Aloëtin.*

B. Amorphous—

a. No precipitate with gold chloride when residue is dissolved in water.

1. Tannin gives no precipitate, residue sharp tasting.

α. Sulphuric acid colours red brown, *Capsicin.*

β. Sulphuric acid colours brown, *Daphne bitter.*

2. Tannin precipitates the aqueous solution; residue bitter or bitterish.

I. Basic lead acetate causes slight turbidity; sulphuric acid and sugar hardly redden.

aa. Ferric chloride gives brown green tint on warming aqueous solution, slightly bitterish; *Gentian leaves.*

bb. Ferric chloride gives brown tint on warming; peculiar taste intolerably bitter, *Quassin.*

II. Basic lead acetate gives copious precipitate; sulphuric acid and sugar quickly give cherry-red tint; weakly bitterish, *Cnicin.*

b. Aqueous residue of solution does not act on gold chloride in the cold, but reduces on warming.

α. Tannin slightly precipitates; does not reduce ammoniacal silver solution; heated with dilute sulphuric acid gives odour of *ericinol;* FRÖHDE'S reagent colours it black-brown; sulphuric acid and sugar a beautiful red, *Ledum bitter.*

β. Tannin precipitates; ammoniacal silver reduced; heated with dilute sulphuric acid gives a slight odour of menyanthol, *Trifolium bitter.*

c. Aqueous solution of residue precipitates gold chloride in the cold, but does not reduce it on heating; with $H_2SO_4 + 5H_2O$ gives a slight odour of benzoic acid, *Centaury bitter.*

d. Aqueous solution of residue precipitates gold chloride in the cold, and reduces it on warming; sulphuric acid dissolves to a brown tint at first, soon turning violet, and becoming a beautiful violet on addition of water; hydrochloric acid of sp. grav. 1·135, colours it first green and then a beautiful blue, *Absinthin.*

Residue from Chloroform—

A. No precipitate and no reduction with gold chloride.

a. Tannin gives no precipitate; sharp taste; epispastic; sulphuric acid colours dark brown red, *Capsicin.*

b. Tannin precipitates.

α. Basic lead acetate gives considerable precipitate; heated with sulphuric acid it becomes turbid, then brown-red, giving a faint odour of benzoic acid, *Cnicin.*

β. Basic lead acetate gives little or no precipitate.

I. Sulphuric acid gives a brown colour.

aa. Residue very bitter, *Quassin.*

bb. Residue bitterish, *Gentian.*

cc. Residue sharp-tasting, *Daphne bitter.*

II. Sulphuric acid gives a slight yellow tint, or no colour at all, *Colocynth.*

B. Gold chloride gives no precipitate in the cold, but is reduced on warming.

a. Tannin does not precipitate.

1. Stupefies fish; bitter taste, *Picrotoxin.*

2. Tasteless or slightly bitter; potash colours red-brown, *Aloes.*

b. Tannin precipitates.

α. Ammoniacal silver reduced; strong odour of menyanthol on heating with sulphuric acid, or FRÖHDE'S reagent, *Menyanthin.*

β. Ammoniacal silver not reduced; odour of ericinol with dilute sulphuric acid, or with FRÖHDE'S reagent; beautiful carmine red on long standing with sulphuric acid and sugar, *Ericolin.*

C. Gold chloride precipitates in the cold, and is not reduced on warming; nitric acid gives a violet tint, *Colchicum.*

Heated with sulphuric acid, gives an odour like trifolium, then the liquid becomes red, and the smell alters to one resembling benzoic acid, *Centaury bitter.*

D. Gold chloride precipitates in the cold, and reduces on heating; sulphuric acid colours brown, and gradually dirty violet, *Wormwood bittter.*

Extract from Alkaline Liquor.

I. *Benzene Residue.*

a. Dilates the pupil of a cat's eye.

1. Platinum chloride does not precipitate the aqueous solution; peculiar odour on warming with sulphuric acid, *Atropine.*

2. Platinum chloride precipitates when in just the right proportion, *Hyoscyamine.*

b. Does not dilate the pupil of a cat's eye.

1. Sulphuric acid solution becomes blue with bichromate of potassium or ceric oxide, *Strychnine.*

2. Sulphuric acid solution becomes red with nitric acid, *Brucine.*

II. *Amylic Alcohol residue* (examined only when salicin is to be sought for).

Heated with sulphuric acid and bichromate of potassium gives a salicilous odour, *Salicin.*

Ash of Beer.—The following are examples of the percentage composition of the ash of beer, the first three analysed by WALZ, the rest by DICKSON:—

	London Beer.	München Beer.	Speyer Beer.	Scotch Ale (14 samples).	Scotch Porter (2 samples).	Dublin Porter (2 samples).	London Porter (5 samples).
Potash,..................	38·35	36·58	37·68	3·2 — 29·8	18·9 — 20·9	21·4 — 32·0	4·9 — 31·1
Soda,..................	7·68	9·03	6·59	20·9 — 38·5	33·8 — 38·8	24·0 — 42·7	21·8 — 50·8
Lime,..................	2·45	1·48	2·98	0·2 — 2·0	1·3 — 1·6	0·8 — 1·5	0·8 — 6·9
Magnesia,..............	3·78	5·64	4·66	0·1 — 5·6	0·2 — 1·4	0·2 — 1·2	0·1 — 1·2
Sulphuric acid (SO_3),.....	1·36	1·68	2·56	1·6 — 19·2	2·2 — 6·4	2·8 — 10·1	1·6 — 12·2
Chlorine,..............	2·75	3·14	2·14	4·3 — 18·25	7·4 — 11·4	6·9 — 10·1	6·5 — 14·5
Silica,..................	9·87	9·96	10·29	4·6 — 19·1	13·3 — 18·6	6·9 — 19·7	8·25 — 19·7
Phosphoric acid (P_2O_5),...	33·76	31·69	33·10	6·0 — 25·7	12·2 — 18·8	7·9 — 20·0	9·3 — 20·6
	100·00	100·00	100·00				

The following tables from WATT'S "Dict. of Chemistry," vol. i. p. 533, exhibit the composition of various kinds of beer:—

AVERAGE AMOUNT OF MALT EXTRACT AND ALCOHOL.

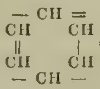
Name of Beer.	Percentage of Malt Extract.	Percentage of Alcohol.
London Ale, for exportation,.	7 — 5	6 — 8
London Ale, ordinary,......	5 — 4	4 — 5
London Porter, for exportation,	7 — 6	5 — 6
London Porter, ordinary,....	5 — 4	3 — 4
Brussels Lambick,..........	5·5 — 3·5	4·5 — 6
Brussels Faro,....	5 — 3	2·5 — 4
Bière Forte de Strasbourg,...	4 — 3·5	4 — 4·5
Bière Blanche de Paris,... ..	8 — 5	3·5 — 4
Bavarian Beer,..	6·5 — 4	3 — 4·5
White Beer of Berlin, ...	6·2 — 5·7	1·8 — 2

SPECIAL RESULTS OF THE EXAMINATION OF CERTAIN BEERS.

Name of Beer.	Malt Extract. per cent.	Alcohol. per cent.	Carbonic Acid. per cent.	Water per cent.	Analysed by
London Porter (Barclay & Perkins),....	6·0	5·4	0·16	88·44	Kaiser.
London Porter, ...	6·8	6·9	*	86·3	Balling.
London Porter (Berlin), .	5·9	4·7	0·37	89·0	Ziurek.
Burton Ale, ...	14·5	5·9	*	79·6	Hoffmann.
Scotch Ale (Edinburgh).	10·9	8·5	0·15	80·45	Kaiser.
Ale (Berlin), ...	6·3	7·6	0·17	85·93	Ziurek.
Brussels Lambick, ...	3·4	5·5	0·2	90·9	Kaiser.
Brussels Faro,..........	2·9	4·9	0·2	92·0	Kaiser.
Salvator Bier (München),	9 4	4·6	0·18	85·85	Kaiser.
Bock Bier (München), ..	9·2	4·2	0·17	86·49	Kaiser.
Bavarian Draught Beer (*Schenk Bier*, München),.............	5·8	3·8	0·14	90·26	Kaiser.
Bavarian Store Beer (*Lager Bier*, München), 16 months old,	5·0	5·1	0·15	89·75	Kaiser.
Bavarian Store Beer (München),........	3·9	4·3	0·16	91·64	Kaiser.
Bavarian Draught Beer (Brunswick), ...	5·4	3·5	*	91·1	Otto.
Bavarian Beer (Waldschlösschen),.......	4·8	3·6	*	91·5	Fischer.
Prague Draught Beer, ..	6·9	2·4	*	90·7	Balling.
Prague Town-beer (*Stadt-bier*),........	10·9	3·9	*	85·2	Balling.
Sweet Beer (Brunswick).	14·0	1·36	*	84·7	Otto.
Josty's Beer (Berlin).....	2·6	2·6	0·5	94·3	Ziurek.
Werder's Brown Beer (Berlin),...........	3·1	2·3	0·3	94·2	Ziurek.
White Beer (Berlin),...	5·7	1·9	0·6	91·8	Ziurek.
Bière Blanche de Louvain,	3·0	4·0	*	93·0	Le Cambre.
Petermann (Louvain),...	4·0	6·5	*	89·5	Le Cambre.
Mum (Brunswick)......	45·0	1·9	*	53·1	Freytag and Busse.

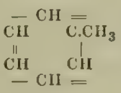
BENZOL.—The term "benzol" is commercially applied to a mixture of bodies, for the most part consisting of the hydrocarbon benzene† and its higher homologues.

The mutual relations of bodies of this description are conveniently indicated by a symbolic device introduced by KEKULÉ. The quantitative analysis of the hydrocarbon benzene is capable of being indicated by the empirical formula, CH; but as its vapour density is found to be 39 times that of hydrogen, the rational formula, C_6H_6, is applied to it in accordance with modern conventions. KEKULÉ has pointed out that the chemical changes occurring with the numerous class of substances known as the "benzene derivatives," or "aromatic compounds," may be conveniently expressed in brief by breaking up or dissecting the rational formula of benzene into six trivalent groups of symbols (radicals) arranged symmetrically thus—

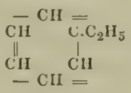

*

the formulæ of benzene derivatives being deducible from this parent formula by replacing, by other radicals, an equivalent number of H symbols. When the radicals thus caused to replace H symbols are univalent hydrocarbon radicals of the methyl series, the formula of higher homologues of benzene are obtained; these and other analogous radicals are referred to as lateral chains of symbols; or, briefly, lateral chains:—

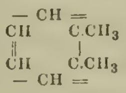
Toluene.



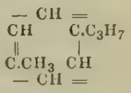
Ethyl Benzene.



[illegible] Dimethyl Benzene.



[illegible] Propyl Methyl Benzene.



It is noteworthy that the homologues of benzene that make up the main portion of commercial benzol are all related to benzene in this way, that the lateral chains in these formulæ always consist of the radical methyl, CH_3, and not of any higher homologous radical; it is, in fact, not proved with certainty that any other kinds of homologues are present, at any rate in coal-tar benzols. Ethyl benzene and methyl-ethyl benzene are stated to exist in these oils, but the evidence of their presence is as yet very incomplete; these and other analogously constituted bodies are therefore omitted from the following list of constituents of benzol:—

Name.	Rational formula.	Partially dissected formula.	Boiling point.	Melting point.
Benzene, ...	C_6H_6		80	+5°·5
Toluene,........	C_7H_8	$C_6H_5.CH_3$	111	Not solid at —20°
Xylene,........	C_8H_{10}	$C_6H_4\left\{\begin{matrix}CH_3\\CH_3\end{matrix}\right.$	139	
Isoxylene,......	C_8H_{10}	$C_6H_4\left\{\begin{matrix}CH_3\\CH_3\end{matrix}\right.$	137 — 138	
Pseudo-cumene,	C_9H_{12}	$C_6H_3\left\{\begin{matrix}CH_3\\CH_3\\CH_3\end{matrix}\right.$	166°	
Mesitylene, ...	C_9H_{12}	$C_6H_3\left\{\begin{matrix}CH_3\\CH_3\\CH_3\end{matrix}\right.$	163°	
Tetra-methyl benzene,....	$C_{10}H_{14}$	$C_6H_2\left\{\begin{matrix}CH_3\\CH_3\\CH_3\\CH_3\end{matrix}\right.$	About 180°	

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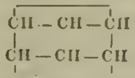
* Not determined quantitatively.

† It is convenient to apply, wherever practicable, a name terminating in *ene* to a hydrocarbon (*e g.*, ethylene, benzene, terpene, anthracene, naphthalene, &c.), the terminal *ol* being applied to bodies containing oxygen (*e.g.*, alcohol, phenol, absinthol, thymol, &c.). The word "benzol" is here applied to the commercial mixture of hydrocarbons, and not to any one constituent of the mixture.

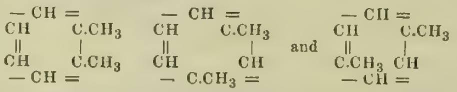
* Another dissected formula, also consisting of six trivalent radicals, is sometimes applied to benzene, viz.:—



this only differs from the hexagonal formula in certain minor respects, and for most purposes may be regarded as identical therewith.

It is noticeable that in this list two different bodies occur, each denoted by the partially dissected formula, $C_6H_4 \left\{\begin{matrix}CH_3\\CH_3\end{matrix}\right.$; and also two, each indicated by $C_6H_3 \left\{\begin{matrix}CH_3\\CH_3\\CH_3\end{matrix}\right.$; a third isomeride of the former pair is also known (but not with certainty as a constituent of benzol), indicated by the same formula, $C_6H_4 \left\{\begin{matrix}CH_3\\CH_3\end{matrix}\right.$; this body boils at 140° to 141° C.

KEKULÉ'S notation affords a most convenient mode of distinguishing between such isomerides, when neither the rational nor the partly dissected formula enables any distinction to be made; moreover, the number of isomerides of any given kind actually known with certainty is never greater than the number that can be thus indicated. All the H symbols in the hexagonal benzene formula being of equal function, it is manifest that the same formula results when only one H symbol is replaced by a given radical, no matter which of the six symbols be operated on; in practice, no isomerism in benzene derivatives of this class is known. When, however, two H symbols are thus replaced, three distinct formulæ result, according as the two H symbols operated on are adjacent, next but one, or opposite to each other; thus the three dimethyl benzenes referred to may be distinguished by the respective formulæ.



In the same kind of way, when three H symbols are replaced, numerous formulæ may be written, differing in the relative positions occupied in the formula by the lateral chains, or radicals substituted for H symbols. The number of formulæ ascribable to any given kind of derivative is as yet never less than the number of distinct isomerides of that kind actually known with certainty.

To distinguish briefly between such bodies as the above dimethyl-benzenes the terms 1.2. dimethyl benzene, 1.3. dimethyl benzene, 1.4. dimethyl benzene, are used according to the relative positions of the lateral chains. The prefixes ortho, meta, and para, are also employed to distinguish between the three formulæ ascribable to benzene derivatives where two H symbols are replaced. Unfortunately chemists are not in accord as to which prefix is to be applied to the 1.2. 1.3. 1.4. formulæ respectively, some applying ortho to the first and meta to the second, others *vice versa;* hence it is preferable to apply these prefixes not in reference to the position of the radicals, or the formula ascribed to the body (which in many instances is quite arbitrary), but according as the body can be transformed by reactions of exchange into one or other of three isomeric varieties of a given class of derivatives, *e.g.:*—

Dihydroxyl benzene.

Ortho,..........	$C_6H_4(OH)(OH)_o$,	Hydroquinone.
Meta,..........	$C_6H_4(OH)(OH)_m$,	Pyrocatechin.
Para,..........	$C_6H_4(OH)(OH)_p$,	Resorcin.

Dicarboxyl benzene.

Phthalic acid,................	$C_6H_4 \left\{\begin{matrix}CO_2H\\(CO_2H)_o\end{matrix}\right.$
Isophthalic acid,..............	$C_6H_4 \left\{\begin{matrix}CO_2H\\(CO_2H)_m\end{matrix}\right.$
Terephthalic,................	$C_6H_4 \left\{\begin{matrix}CO_2H\\(CO_2H)_p\end{matrix}\right.$

The suffixes *o m p*, applied to the radicals constituting the lateral chains, thus indicate the reactions of the kind undergone by the body in question: thus, the xylene of coal ores boiling at 139° is paradimethyl benzene, $C_6H_4 \left\{\begin{matrix}CH_3\\(CH_3)_p\end{matrix}\right.$ as it yields terephthalic acid by oxidation, whilst the isoxylene simultaneously present is metadimethyl benzene, as it forms isophthalic acid, $C_6H_4 \left\{\begin{matrix}CH_3\\(CH_3)_m\end{matrix}\right.$, by the same process.

A circumstance limiting the utility of this convenient short-hand system is, that it not unfrequently happens that the same substance by one train of reactions gives rise to a body belonging to the, say, para series, and by another series of reactions to one belonging to the, say, meta series: in a case of this kind "alteration of relative position of lateral chains" is said to occur at some one of the stages.

Benzene.—This hydrocarbon was first discovered by FARADAY in 1825, in the liquid which resulted from the compression of illuminating gases produced by the destructive distillation of oil. From its empirical formula, C_2H (where $C = 6$ and $H = 1$), he termed it *bicarburet of hydrogen.* In 1836 MITSCHERLICH obtained it by heating benzoate of calcium, whence the name *benzol* (or *benzene*, as it is now preferably termed. *Vide* p. 341). HOFMANN in 1845 discovered its existence in coal tar, and soon after (1847) MANSFIELD proposed to separate it (in an impure state) therefrom by distillation, in order to employ it as a carburizer for gas of weak illuminating power. Its application to the removal of grease and the manufacture of artificial essence of almonds soon followed; and finally the discovery of aniline dyes caused an enormous increase in the trade in this substance.

Besides occurring in the tar of coals, benzene and its homologues are formed by the destructive distillation of many organic substances, *e.g.*, wood, turf, resin, &c.; and they also occur in various natural petroleums and naphthas, such as Rangoon tar (DE LA RUE and MÜLLER), petroleum of Sehnde, Hanover (BUSSENIUS and EISENSTÜCK), naphtha from Boroslaw, Galicia (PEBAL and FREUND). In the early days of the aniline dye industry attempts were made to utilize some of these sources, but it was soon found that coal tar was a far cheaper and better source. VOGEL examined in 1858 a sample of so-called benzol, which contained much oxidized matter and began to boil at 102°, whilst in the same year SCHIFF found that a specimen contained wood-spirit, methyl acetate, toluene, xylene, and higher homologues, but no trace of benzene!

Benzene is obtainable by heating, in contact with alkalies, any one of the numerous benzene-carboxyl acids. Thus—

$$\text{Benzoic acid,......}C_6H_5 \quad CO.OH = CO_2 + C_6H_6$$

$$\text{Phthalic acid,......}C_6H_4\left\{\begin{matrix}CO.OH\\CO.OH\end{matrix}\right. = 2CO_2 + C_6H_6$$

$$\text{Trimesic acid, ...}C_6H_3\left\{\begin{matrix}CO.OH\\CO.OH\\CO.OH\end{matrix}\right. = 3CO_2 + C_6H_6$$

$$\text{Pyromellitic acid,..}C_6H_2\left\{\begin{matrix}CO.OH\\CO.OH\\CO.OH\\CO.OH\end{matrix}\right. = 4CO_2 + C_6H_6$$

Also, by heating in a sealed tube acetylene, which then polymerizes; $3C_2H_2 = C_6H_6$ (BERTHELOT). Also, by the action of heat on the vapour of many other hydrocarbons, *e.g.*, xylene, chrysene, naphthalene, diphenyl, &c. (BERTHELOT). None of these processes are of practical use. It has been proposed to manufacture pure benzene from naphthalene by oxidizing that hydrocarbon to phthalic acid, and then heating this substance in contact with lime; but it is manifest such a process would be far too costly. Benzoic acid is, however, formed in this way by the intermediate reaction—

$$\overset{\text{Phthalic Acid.}}{C_6H_4\left\{\begin{matrix}CO.OH\\CO.OH\end{matrix}\right.} = CO_2 + \overset{\text{Benzoic Acid.}}{C_6H_5.CO.OH},$$

to an extent sufficient to make it applicable for the manufacture of that body (P. & E. DEPOUILLY).

Pure benzene boils at 80°·4 (KOPP), 80° to 81° (MANSFIELD), 82° (FREUND); it has the specific gravity 0·85 at 15° (FARADAY and MITSCHERLICH), 0·899 at 0° (KOPP); it solidifies, on cooling, to a crystalline mass, which melts at 5°·5; nitric acid converts it into nitrobenzene, $C_6H_5(NO_2)$, and by further action into dinitrobenzene, $C_6H_4(NO_2)_2$: it readily dissolves fatty and essential oils, whence its use for cleaning clothing, and for the extraction of oil and grease from seeds, oil-cake, wool, &c., &c. It is most conveniently obtained pure by fractional distillation of commercial benzol (*vide* p. 345), and successive crystallization of the lowest distillates.

Toluene.—This hydrocarbon was found by PELLETIER and WALTER, in 1838, in the liquid condensed by compressing resin gases, and was described by them under the name of *retinaphtha*. NOAD obtained it in 1847 by heating toluic acid with excess of baryta, its mode of formation being identical with that benzene from benzoic acid; hence the name toluol (or toluene —*vide* p. 341).

$$\overset{\text{Toluic Acid.}}{C_6H_4\left\{\begin{matrix}CH_3\\CO.OH\end{matrix}\right.} = CO_2 + \overset{\text{Toluene.}}{C_6H_5.CH_3}.$$

It is present in coal tar (MANSFIELD, 1847), wood tar (CAHOURS), Rangoon tar (DE LA RUE and MÜLLER), and the product of the distillation of tolu balsam (DEVILLE) and of dragon's blood (GLENARD and BOUDAULT). It can be synthetically formed by the action of sodium on a mixture of phenyl and methyl bromides (FITTIG and TOLLENS)—

$$C_6H_5Br + CH_3Br + Na_2 = 2NaBr + C_6H_5.CH_3;$$

and by the distillation of benzoate and acetate mixed together (BERTHELOT), or by the action of alcoholic caustic potash on benzoic alcohol (CANNIZARO), and by several other reactions.

When required pure and in quantity, it is most conveniently extracted from commercial benzol by fractional distillation (*vide* p. 345); smaller amounts are readily obtainable from dragon's blood or from tolu balsam. Pure toluene much resembles benzene in general properties, save that it does not solidify on cooling to —20°. Its specific gravity is 0·8824 at 0°, and 0·875 at 20°; its boiling point is 110° to 111°. No isomeric modification of it is known;* although it gives rise to two (and possibly three) isomeric nitro-toluenes on nitration; each of these reproduces the same original toluene on reduction by hydriodic acid (ROSENSTIEHL).

Xylene.—Three dimethyl benzenes are known, one of which, orthoxylene, has not yet been shown to exist in coal tar: the other two were confounded together until 1869, when FITTIG showed that coal tar xylene is really a mixture of two isomerides.

Para-xylene, or methyl toluene, is obtainable by the action of sodium on a mixture of brominated toluene and methyl iodide or bromide (FITTIG and GLINZER)—

$$C_6H_4\left\{\begin{matrix}Br\\CH_3\end{matrix}\right. + CH_3Br + 2Na = 2NaBr + C_6H_4\left\{\begin{matrix}CH_3\\CH_3.\end{matrix}\right.$$

Meta-xylene, or isoxylene, is producible by heating mesitylenic acid (formed by the oxidation of mesitylene, $C_6H_3(CH_3)_3$) along with lime, the reaction being parallel to that whereby benzene is formed from benzoic acid or toluene from toluic acid (FITTIG.)

$$C_6H_3\left\{\begin{matrix}CH_3\\CO.OH\\CH_3\end{matrix}\right. = CO_2 + C_6H_4\left\{\begin{matrix}CH_3\\CH_3\end{matrix}\right.$$

or by similarly treating the isomeric xylylic acid (from the oxidation of pseudo cumene).

Ortho-xylene is formed by an analogous reaction, para-xylylic acid (formed along with the isomeric xylylic acid) being used instead of its isomeride (FITTIG and BIEBER). The following table indicates the main points of difference between these three hydrocarbons:—

	Para.	Meta.	Ortho.
Boiling point, ...	139° FITTIG & GLINZER. 136° JANNASCH.*	137° to 138°.	140° to 141°.
Products formed by oxidation with dilute nitric acid, ...	Para-toluic acid, melting at 176°.	Not attacked.	Orthotoluic acid, melting at 102°.
Do. with chromic acid, ...	Terephthalic acid.	Isophthalic acid.	
Trinitro-xylene, ...	Melts at 137°	Melts at 177°.	

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* CHURCH has described a "para-benzene" boiling at 97°·5, and not solidifying at —20°, and a "para-toluene" boiling at 119°·5, occurring in coal tar; the former giving rise to the same nitrobenzene as ordinary benzene boiling at 80°. These results have not been confirmed, and it seems probable that the bodies in question were only very impure benzene and toluene.

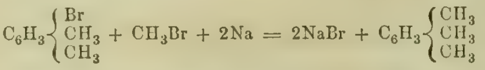
* JANNASCH has recently found (*Zeitsch. f. Chem.* [?] vii. 117) that the xylene obtained from pure solid bromotoluene and methyl iodide (para-xylene) is a solid crystalline substance, melting at 15° and boiling at 136°. Not improbably the bromotoluene used by FITTIG and GLINZER contained a little meta-bromotoluene.

The mixture of isomerides obtained from coal tar has recently been proposed as a remedial agent in cases of small-pox, doses of 3 to 5 drops (children) or 10 to 15 drops (adults) given every hour, or somewhat less frequently, having been found to produce remarkable results in cases of this disease.

Girard and **De Laire** state that ethyl benzene ($C_6H_5.C_2H_5$) exists in that portion of coal oils that passes over between toluene and xylene, but cite no experimental evidence in support of the statement. ("Traité des Derivés de la Houille," Paris, 1873, p. 47). This hydrocarbon boils at 133° to 135°.

Cumene.—Besides other isomerides, not known with certainty to occur in coal tar, two trimethyl benzenes are known occurring in commercial benzol; the discovery of the distinction between these was made by **Fittig** in 1868.

Pseudo cumene, trimethyl benzene, or dimethyl toluene. This substance is obtained in a state of purity by the action of sodium on a mixture of methyl iodide or bromide, and brominated paraxylene. The same substance is produced also if metaxylene is substituted for paraxylene (**Fittig** and **Jannasch.**)



$$C_6H_3\left\{\begin{matrix}Br\\CH_3\\CH_3\end{matrix}\right. + CH_3Br + 2Na = 2NaBr + C_6H_3\left\{\begin{matrix}CH_3\\CH_3\\CH_3\end{matrix}\right.$$

Mesitylene.—This is obtained by the dehydrating action of sulphuric acid, &c., on acetone, and in various other ways, *e.g.*, the action of zinc chloride on camphor.

$$\overset{\text{Acetone.}}{3CO(CH_3)_2} = 3H_2O + \overset{\text{Mesitylene.}}{C_6H_3\,(CH_3)_3}.$$

$$\overset{\text{Camphor.}}{C_{10}H_{16}O} = CH_4O + \overset{\text{Mesitylene.}}{C_6H_3\,(CH_3)_3}.$$

The differences between these two hydrocarbons may be thus contrasted:—

Boiling point,..	Pseudo cumene, 166°	Mesitylene, 163°
Action of dilute nitric acid,..	Forms two isomeric acids, each indicated by $C_9H_{10}O_2$, viz. Xylylic melting at 120° Paraxylylic " " 163° By further action gives xylidic acid, $C_9H_8O_4$	Forms mesitylenic acid, also indicated by $C_9H_{10}O_2$, melting at 166°
Trinitro derivative,	Melts at 185°	Melts at 230° to 232°

Numerous other isomerides are known, *e.g.*, propyl benzene, methyl ethyl benzene, &c., but the occurrence of these in coal tar is not yet proved. By the action of nitrating agents on the mixture of hydrocarbons of formula C_9H_{10}, obtained from coal tar, three trinitro compounds are formed—viz., the trinitro pseudo cumene, and the trinitro mesitylene above mentioned, and also a third modification, melting at a lower temperature than either (**Fittig** and **Wackenroder**); hence it is not impossible that a third modification of the hydrocarbon is therein present. This has not yet been isolated, however, whilst the production of the *three* trinitro bodies is perfectly compatible with the existence of *two* hydrocarbons only.

Tetramethyl Benzene.—The existence of a benzene homologue higher than "cumol" in coal tar was signalized by **Mansfield**; but later researches seemed to indicate that the product thus obtainable by fractional distillation was very impure, containing naphthalene and mesitylene, &c., so that some doubt existed as to the presence at all of tetramethyl benzene in coal tar. **Berthelot**, however, has shown that the hydrocarbon boiling at 179° to 180°, and freed from naphthalene by a treatment with picric acid, has the composition $C_{10}H_{14}$, and differs from ordinary cymene (from cummin oil, camphor, &c.), and other hydrocarbons of formula $C_{10}H_{14}$, in the nature of the products formed by the action of hydriodic acid—viz., nothing but decane ($C_{10}H_{22}$) in the case of the coal-tar product; decane mixed with lower homologues corresponding with the various "lateral chains" present in the formula of the other isomerides, in these cases respectively.

A solid tetramethyl benzene melting at 79° to 80°, and boiling at 189° to 191°, has been obtained recently by **Fittig** and **Jannasch**, by the action of sodium on a mixture of brominated trimethyl benzene (pseudo cumene), and of methyl bromide. The existence of this body, termed *durol* (preferably *durene*, vide note, p. 341) by the discoverers, in coal tar is, however, not yet proved.

Manufacture of Benzol.—In the first rough distillation of tar (*vide* article **Coal-tar Distillation**) two fractions are obtained, known as "first light oils" and "second light oils." These contain considerable quantities of benzene and its homologues, usually consisting of the following ingredients in various proportions:—

	Boiling Point.
Ammonia, sulphide of ammonium, and other ammoniacal compounds,..........................	—
Hydrocarbons homologous with marsh gas, especially hexy hydride,..........................	68°—160°
Hydrocarbons homologous with olefiant gas, especially amylene, hexylene, and heptylene,.......	40°—100°
Benzene,....................................	80°
Toluene,....................................	111°
Higher homologous hydrocarbons,................	137°—180°
Bases of the pyridine series, chiefly pyridine and picoline,....................................	117°—135°
Phenol (carbolic acid),.......................	187°
Higher homologues,..........................	—
Naphthalene,................................	218°
Aniline (traces),.............................	182°

The quantity of substance of boiling point above 150° C. present, varies with the nature of the tar, the way in which the distillation is effected, &c.

To prepare "benzol" from these liquids slightly different methods are employed, according to the quality of the benzol ultimately required. For certain makes of aniline dyes a benzol of which 90 per cent. is volatile below 100° C. is required; for other purposes benzols of 80, 50, 30, &c., per cent., distilling below 100°, are prepared.

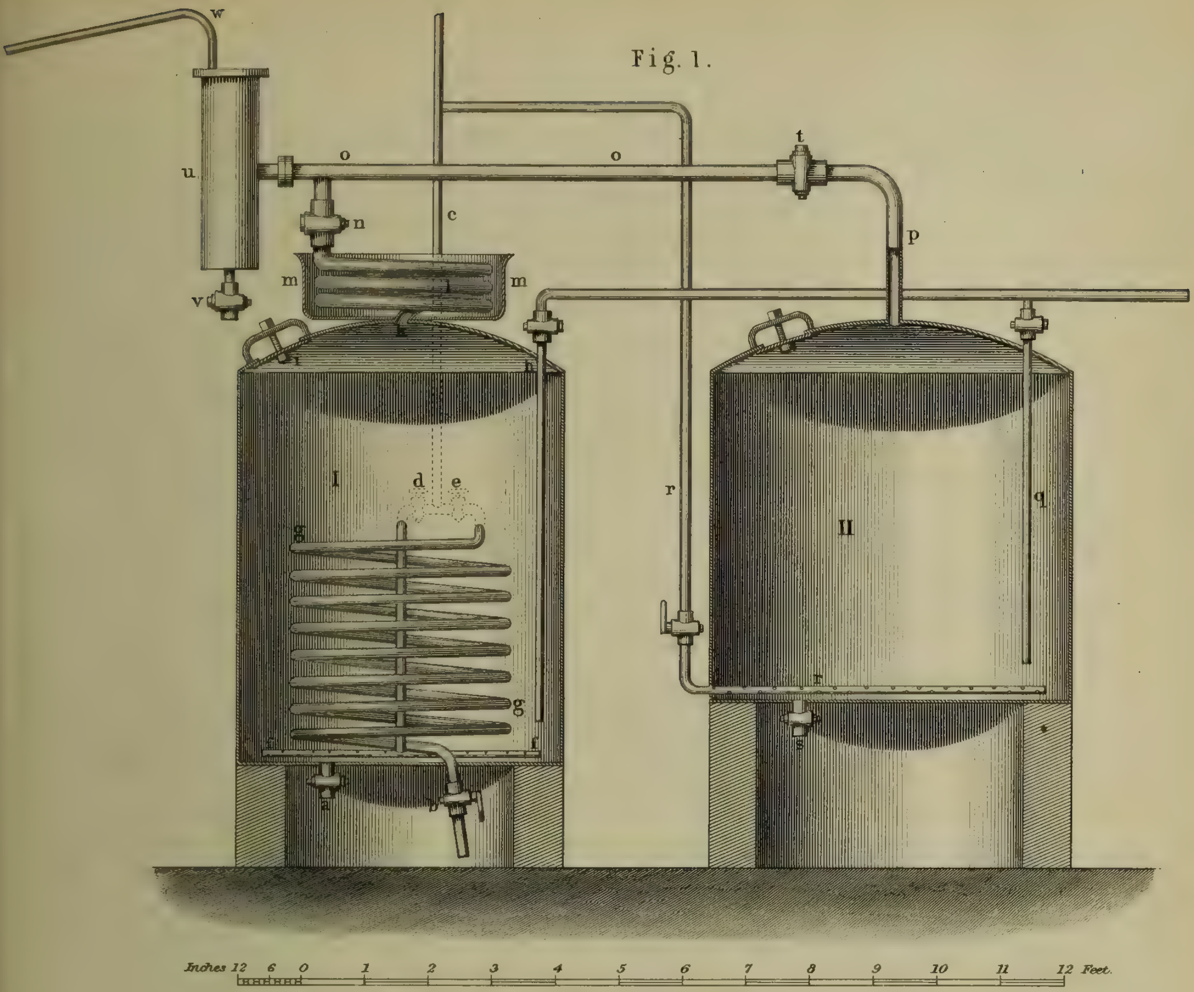
For the former quality the first light oils are usually treated separately; for the others the first and second light oils are mixed together and distilled by "wet steam"; sometimes the second light oils are thus distilled by wet steam, and the distillate treated along with the first light oils for 90 per cent.

BENZOL.

PLATE 1.

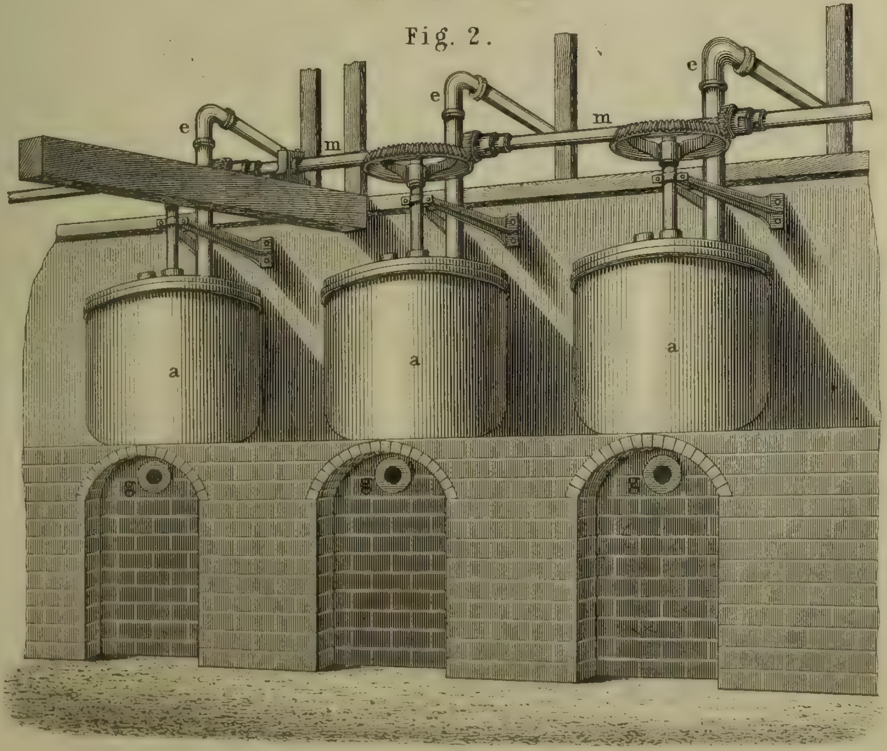
STILLS.

Fig. 1.



Scale 1 Inch = 3 Feet.

Fig. 2.



J. B. LIPPINCOTT & CO. PHILADELPHIA.

benzols. By redistilling the "once run naphtha" thus obtained by means of wet steam in a still heated by a dry steam-worm, benzols of any required percentages may be obtained according to the temperature up to which the distillation is carried, which is known by means of a thermometer adjusted in the roof of the still, so that the temperature of the evolved vapour can be read off.

Besides benzol, the light oils contain another valuable constituent, viz., carbolic acid, which, together with various impurities, is usually removed from them by treatment with alkalies (lime, caustic-soda, soda-ash, &c.) and sulphuric acid before the extraction of benzol is proceeded with. For this purpose the light oils are mashed with about 5 per cent. of strong sulphuric acid in a lead-lined tub, furnished with an agitator worked by hand or by steam. Ammonia, pyridine, and other bases, and a portion of the ethylene homologues are thus dissolved out. Preferably the ammoniacal benzene may be treated with water first, so as to wash out ammoniacal compounds: this water can be used, together with the ordinary gas liquor, for making sulphate of ammonia. After standing some hours the acid is run off through a tap at the bottom of the tub; if necessary, a second treatment with sulphuric acid is proceeded with, the acid run off from this second process serving to purify another batch of hydrocarbon. Water, with which lime is stirred up (milk of lime), is then added, and the whole agitated for some time: carbolic acid, particles of sulphuric acid, &c., are thus removed. Finally, the hydrocarbon is washed with water, and after standing, run off to a still for a final distillation. Some manufacturers prefer to use either soda-ash or caustic-soda instead of lime; the last is, however, cheaper. GIRARD and DE LAIRE recommend the use of three cast-iron cylindrical tubs 1·6 mètre high and 2 in diameter, arranged at such levels that the oils drop into the first from the condenser, and can thence be run into the second and thence into the third by gravitation. In the first tub the hydrocarbon is agitated with water, which is run off by a syphon after standing: the hydrocarbon is then run into No. 2, which is lined with lead (soldered by the hydrogen blow-pipe) and furnished with a lead-covered agitator and with a kind of lid pierced all over with small holes. This tub serves for the sulphuric acid treatment, the object of the pierced lid being to divide the acid into small streams as it enters. A second treatment with acid is given if required, the spent acid being run off through a tap at bottom, and the hydrocarbon is then washed three or four times with water. Finally, it is run into No. 3, where it is treated with 2 to 3 per cent. of caustic-soda ley, at a specific gravity, 1·305; after thorough agitation, and twelve hours' repose, the spent ley is run off, and the hydrocarbon washed twice with pure water, being allowed to stand six hours after agitation in each case. ("Traité des Derivés de la Houille," 1873.)

It is scarcely necessary to say that, owing to the volatility and inflammability of the benzol, all the tubs must be covered closely; lids fitting on with water-lutes and pierced with a hole fitting to the agitator spindle are preferable.

According to the nature of the contracts on hand, or of the purposes to which the benzol is to be put, so the temperatures at which the distillates are collected are regulated. For the purpose of fuchsine making a benzol is required which will yield (by nitration and subsequent reduction) an aniline oil of which about three quarters distil between 180° and 190°, and one quarter between 190° and 215°; such an aniline oil is obtained from a benzol, of which about three quarters distil between 80° and 100°, and one quarter between 100° and 130° (REIMANN). For methyl violet, on the other hand, an aniline as free as possible from higher homologues is requisite, and this is made from a benzol very little of which passes over above 83° or 84°. Not unfrequently, however, colour manufacturers prepare aniline oils of various character from benzols of tolerably constant character supplied by contract, or prepared by a uniform process on the premises, these oils being then mixed in such proportions as may be required for the end in view.

For certain colours, *e.g.*, xylidine red, only aniline oils of very high boiling point are used. These come from benzols boiling above 115° or 120°; but it is more usual to prepare these special aniline oils by distillation of commercial aniline oils, reserving the last portions of high boiling point (*aniline tailings*, or *queues d'aniline*), than to prepare them from special benzols.

LETHEBY thus describes the distillation of benzol as carried on near London:—Steam is blown through the light oils (first and second mixed) at 20 to 30 lbs.; the once run naphtha thus produced is purified by sulphuric acid, &c., and then again distilled by blowing high pressure steam through, the distillate being collected in three fractions: the first is called "80 per cent. benzol," the second "50 per cent. benzol," whilst the last portions are used for dissolving indiarubber, &c., and are known as "solvent naphtha." The 50 per cent. benzol is distilled from a steam-jacketted still, that distilling up to a temperature of 210° being 80 per cent. benzol, and that between 210° and 260° 30 per cent.; the residuum is blown over with wet steam and added to the solvent naphtha. The 30 per cent. distillate is again distilled by dry steam, when it yields a little 80 per cent., distilling below 106°; between 106° and 234° 40 per cent. benzol passes over; and between 234° and 260° a little 30 per cent., a residuum of solvent naphtha blown over by wet steam being left; thus the oils are split up into 80 per cent. benzol, 40 per cent., and solvent naphtha. Finally, the 80 per cent. benzol is again distilled by dry steam; that passing over up to 104° is sold as 90 per cent. benzol; that between 204° and 210° is 80 per cent.; whilst the residue is blown over by steam and furnishes more 40 per cent. benzol.

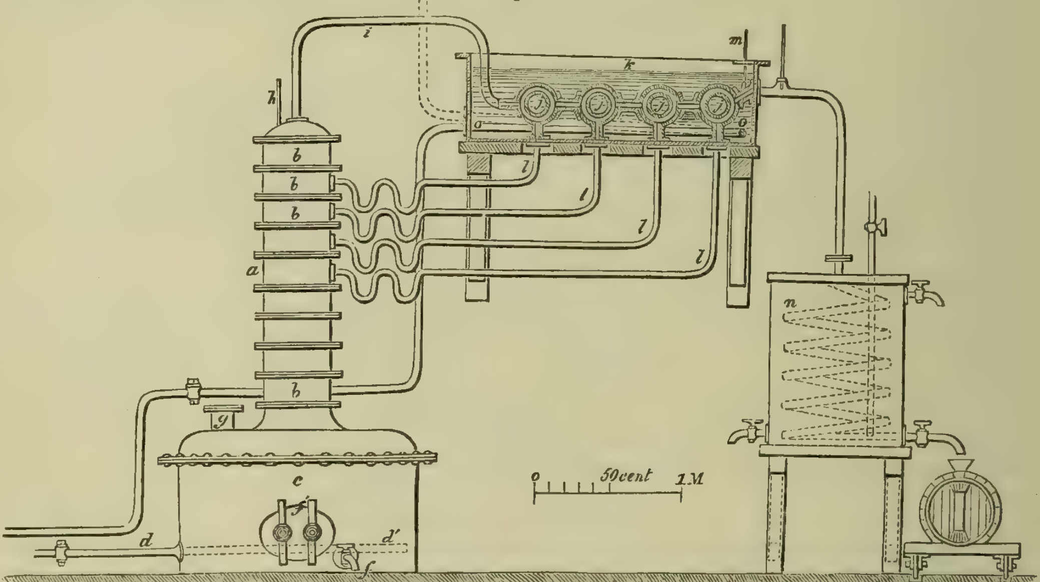
For this kind of operation the following kind of double still may be employed—Still I. being used for the more volatile fractions, and II. for the higher boiling portions. (BENZOL, Plate I.):—I. Cylindrical still; *a*, drawing-off cock; *b*, cock for drawing off condensed water from steam worm, *g g*; *c*, steam pipe; *d e*, cocks for connecting steam either with worm, *g g*, or with pipe, *f f*; *f f*, horizontal serpentine pierced with holes so as to blow steam through the still when required; *g g*, steam worm for heating still without admission of steam to the interior; *h*, pipe whereby the hydrocarbons are run into the still; *i*, manhole; *k*, exit pipe for hydrocarbon vapours; *l*, serpentine immersed in a tank of water, *m m*; *m m*, water tank for condensation of those constituents of evolved vapour which boil above 100°; *n*, cock for shutting off connection of still and condenser; *u*, receptacle for liquid spirted over; *v*, tap for drawing off liquid from *u*; *w*, pipe leading to condenser. II. Cylindrical still; *o o*, pipe leading to condenser; *p*, exit pipe for vapours; *q*, pipe whereby hydrocarbons are run into still; *r r*, horizontal serpentine pierced with holes so as to blow steam through still when required; *s*, drawing-off cock; *t*, cock for shutting off connection of still and condenser.

Still I. is 5 feet wide and 6 high, while II. is 5½ feet wide and only 5 high; the two stills, moreover, differ in that I. is provided with the steam worm, *g g* (which has fifteen turns, not all shown in the figure), and also with the condensation tank, *m m*.

When the lighter distillates are to be rectified, the cock, *t*, is closed and *n* opened; steam is let into the worm, *g g*, and the distillation effected. To blow over the last portions, the worm, *g g*, is shut off, and steam is blown in directly through the worm, *f f*. In distilling the higher boiling portions from II., the steam is simply blown in through *r r*, the cock, *t*, being opened and *n* being shut off.

Girard and De Laire recommend as most convenient the following form of still, more especially for the final distillations of purified benzols. This still consists of a wrought or cast iron cylinder, about 1·8 mètre high and 2 in diameter, and holding 1000 to 2500 litres, resting on a solid brick and cement foundation; it is heated by a worm-tube of iron or lead through which steam at 3 to 4 atmospheres is passed; the passing over of the hydrocarbon is much facilitated by the injection of a jet of steam, but in this case the thermometer cannot be used as an indicator of the progress of the distillation, and hence fractional distillation is rendered impossible.

Fig. 1.



A process of fractional condensation, originally proposed by Mansfield in 1847 (Patent No. 11960, November 11, 1847), has been applied by Coupier to the commercial preparation of hydrocarbons of the benzene family in a state of considerable purity. This consists in passing the vapour from the still through a worm, or a series of bulbs, immersed in a hot bath (water, saline solution, oil, paraffin, &c.), kept a temperature a little below the boiling point of the most volatile to be isolated; the less volatile vapours are thereby condensed and fall back into the still, whilst the most volatile body passes on, and is condensed in a separate worm-tube. Thus in the diagram, Fig. 1, the vapour generated in the still *c* passes upwards through the vertical column, *a*, which is fitted internally with shelves, *b b b*, pierced with holes; the ascending vapour is here well scrubbed with the liquor already condensed; the vapour then passes through the condensers, *j j j j*, which are immersed in a tank, *k*, heated to the required temperature by means of a steam worm, *o o*; the condensed liquid runs back into the still through the pipes, *l l l l*, whilst the uncondensed vapour passes on to the worm, *n*, and is there condensed. (*a*, tower; *b b b*, shelves pierced with holes; *c*, still heated by a steam worm, *d*; *d d*, steam worm; *f*, cock for emptying still; *f′g*, manholes; *h*, thermometer for reading off the temperature of the vapour at the top of the tower; *i*, tube leading vapours from tower to condensers; *j j j j*, condensers immersed in a tank of hot water, &c.; *k*, tank containing hot liquid; *l l l l*, reflex tubes for liquids condensed in *j* to pass back to the still; *m*, thermometer in tank; *n*, worm tube well cooled; *o o*, steam worm to heat tank *k*. Figs. 2 and 3 represent the arrangement of the perforated shelves, *b b b*, whereby the ascending vapour is "scrubbed" with the liquor already condensed. *b'b'*, sections of perforated shelves; *p p p p*, partition walls not reaching wholly across, but arranged so as to cause the vapour to travel horizontally; *q q q q*, pipes perforated with holes into which the vapour ascends; *r*, boss against which the vapour impinges; *s s*, overflow pipe through which the condensed liquid drops down into next lower compartment).

In the distillation of benzol, so as to separate approximately benzene, toluene, &c., the liquid to be distilled is heated by a steam worm, *d d'*, at about 2 atmospheres pressure; the tank, *k*, being kept at 60° to 70°, all toluene and higher homologues are condensed by the worms, *j j j j*, whilst the benzene vapour passes on to *n*. When all the benzene (or nearly all) has thus passed over, the tank, *k*, is heated to 100° to 105°, and the pressure of steam in the still increased to 3½ atmospheres; a small quantity of toluene, mixed with the residual benzene, now passes over to *n*, and in a short time commercially pure toluene only is obtained. Similarly when nearly all the toluene is separated, "xylene" and "cumene" may be similarly separated, the steam pressure on the still being raised to 6 or 7 atmospheres, and the tank, *k*, being heated to a few degrees below 138° and 165° respectively; for this purpose, a strong solution of ammonium nitrate is used in the tank.

Fig. 2.

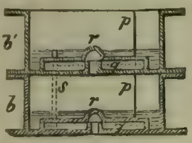
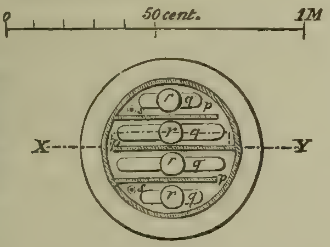


Fig. 3.



From 100 litres of benzol, wholly distilling between 62° and 150°, the following quantities of distillates may be obtained by this apparatus (COUPIER):—

Nature of Distillate.	Litres condensed in *n*.	Boiling Point.
Mixture of benzene and lower boiling substances,........	6	62°— 80°
Nearly pure benzene,..........	44	80°— 82°
Mixture of benzene and toluene,	6	82°—110°
Nearly pure toluene,..........	17	110°—112°
Mixture of toluene and xylene,.	5	112°—137°
Nearly pure xylene,.....	9	137°—140°
Mixture of xylene and higher homologues,.............	5	140°—148°
" (?)	8	148°—150°
	100	

These figures may be represented graphically by the following diagram, where the ordinates are the boiling temperatures, and the abscissæ the bulks of the distillate (Fig. 4).

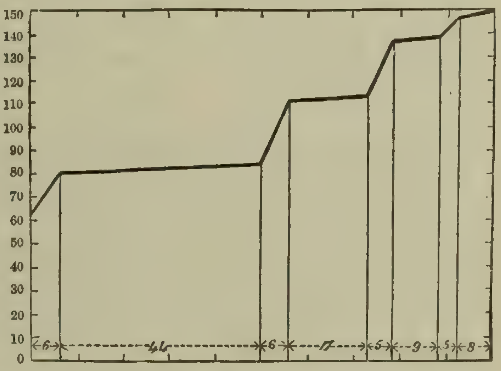
The benzol still, I., depicted Plate I., is an adaptation of MANSFIELD'S principle. In practice the tank, *m m*, is kept filled with water, whereby benzol, distilling almost wholly (90 to 95 per cent.) below 100°, can be readily obtained. Of course COUPIER'S processes may be carried out with this arrangement to a considerable extent, whenever requisite.

Analogous adaptations of MANSFIELD'S principles have also been patented by others; *e.g.*, CLARK (Specification, June 5, 1863, No. 1405).

When exceedingly pure benzol (consisting of little but benzene) is required, as for the preparation of *essence de mirbane* for perfumery, or for the production of an aniline oil containing little but aniline, the benzol (already purified considerably by distillation and separate collection of the portions boiling between 80° and 85°) is cooled down to 0° or lower, and the resulting solid mass submitted to pressure; the residual crystals are benzene in a state of considerable purity, melting at + 5°·5. For extra pure specimens the freezing process may be repeated.

Derivatives of Benzene and its Homologues.—Out of the enormous numbers of bodies of this nature, comparatively few have as yet met with industrial applications; of these many are naturally occurring products, and in many instances the agreeable odour they possess leads to their use in perfumery. Some few have a medicinal value; others, such as carbolic acid, meet with special applications on account of their peculiar properties. Descriptions of those derivatives that are employed in the arts and manufactures will be found under their special names.

Fig. 4.



By oxidation the benzene hydrocarbons usually give rise to acids; thus:—

Toluene.

$$2C_6H_5.CH_3 + 3O_2 = 2C_6H_5.CO_2H + 2H_2O$$

Dimethyl benzene.

$$C_6H_4\left\{\begin{matrix}CH_3\\CH_3\end{matrix}\right. + 3O_2 = C_6H_4\left\{\begin{matrix}CO_2H\\CO_2H\end{matrix}\right. + 2H_2O, \&c., \&c.$$

No industrial application is made of this kind of reaction, but a somewhat analogous change is utilized in the artificial production of benzoyl hydride, or oil of bitter almonds. When toluene is chlorinated, amongst other products there is found benzyl chloride, to which the formula $C_6H_5.CH_2Cl$ is applied. When this is treated with dilute nitric acid, or better, lead nitrate, it becomes converted for the most part into benzoyl hydride; thus—

$$2C_6H_5.CH_2Cl + O_2 = 2C_6H_5.COH + 2HCl.$$

(*Vide* p. 351.)

One class of benzene derivatives, however, is of great commercial importance, viz., the bodies which result from the action of concentrated nitric acid on the hydrocarbons; mixtures of these products constitute the *nitrobenzol* of commerce, the source of aniline and the dyes thence derived (*q. v.*).

The formation of the main constituents of this commercial product may be exemplified by the following equation; small quantities of other derivatives (dinitro- trinitro- bodies, &c.) are also present.

$$C_6H_x\,(CH_3)_{6-x} + NO_2OH = HOH + C_6H_{x-1}\,(CH_3)_{6-x}\,(NO_2).$$

Thus the following bodies are present in commercial nitrobenzol:—

		Boiling Point.	
X = 6	Nitrobenzene $C_6H_5(NO_2)$	205—219	various observers.
X = 5	Para nitro-toluene......... $C_6H_4(CH_3)p(NO_2)$................	235—226	BEILSTEIN and KUHLBERG.
X = 5	Meta nitro-toluene........ $C_6H_4(CH_3)m(NO^2)$...............	222—223	do.
X = 4	Various nitro-xylenes.... $C_6H_3(CH_3)_2(NO_2)$...............	near 240°	
X = 3	Various nitro cumenes... $C_6H_2(CH_3)_3(NO_2)$..............	250—265	

Ortho-nitro-toluene is also known, but its presence in nitrobenzol is as yet unproved; the various probable isomerides of nitroxylene and nitrocumene have not yet been thoroughly investigated.

Each one of these substances, when in conjunction with reducing agents, such as nascent hydrogen, undergoes the following reaction, thereby giving rise to the "aniline base" corresponding to the nitro compound employed:—

$$C_6H_{x-1}\,(CH_3)_{6-x}\,(NO_2) + 3H_2 = 2H_2O + C_6H_{x-1}\,(CH_3)_{6-x}\,(NH_2).$$

The aniline bases thus produced have been already discussed (*vide* ANILINE), and their mode of manufacture described; it only remains, therefore, to give the description of the processes employed in the commercial production of nitrobenzol, and of the general properties of the constituents of this body.

Nitrobenzene.—This body was discovered by MITSCHERLICH in 1834. When pure it forms a colourless liquid of odour resembling oil of bitter almonds, and of specific gravity 1·209 at 15° (MITSCHERLICH), 1·1866 at 14°·4 (KOPP); it boils at a temperature variously stated by different observers, *e.g.*, 205° (KEKULÉ), 213° (MITSCHERLICH), and 219° (KOPP); it solidifies to a crystalline mass between 0° and + 3°. It constitutes the main constituent of the *essence de mirbane* used in perfumery, which is prepared by the same processes as commercial nitrobenzol, only from nearly pure benzene (*vide* p. 349). This manufacture was first proposed by MANSFIELD, who patented the production of an artificial oil of almonds in 1847; in the succeeding year PELOUZE and COLAS commenced making it for this purpose in Paris; but the demand was small and the production limited, until the invention of aniline dyes called for the production of aniline on the large scale. It is slightly soluble in water (100 of water dissolve 0·18 parts of nitrobenzene), addition of common salt precipitates most of the oil thus taken up; dilute acids dissolve it somewhat more readily, whilst alcohol, ether, benzene, and its homologues dissolve it easily.

The higher homologues of nitrobenzene, viz., the *nitrotoluenes*, *nitroxylenes*, and *nitrocumenes*, exhibit, so far as they have been investigated, considerable resemblance to the parent body nitrobenzene; on nitration, toluene gives rise to para and meta nitrotoluene simultaneously, from which para and meta toluidine are respectively obtainable. Ortho-nitrotoluene has been obtained by BEILSTEIN and KUHLBERG by acting with alcoholic potash on nitro-paracet-toluide, whereby a nitrotoluidine is obtained; on acting with nitrous acid on this compound a diazo-derivative results, which yields ortho-nitrotoluene on boiling with alcohol (meta-nitrotoluene is obtainable in the same way from the corresponding diazo-derivative of the nitrotoluidine resulting from the reduction of dinitrotoluene melting at 70°·5). These three isomerides may be thus contrasted.

	Para.	Meta.	Ortho.
At ordinary temperatures,..	Solid.	Liquid.	Liquid.
Melting point,............	54°	—	Solidifies in freezing mixture. and then melts at + 16°
Boiling point,............	235° to 236°	222° to 223°	230° to 231°
Specific gravity,..........	—	1·163 at 23°·5.	1·168 at 22°
Action of chromic acid,...	Readily oxidized, forming para-nitro-benzoic acid (nitro - dracylic acid), melting at 240°.	Scarcely any action, even after boiling for several days.	Readily oxidized to ortho-nitro-benzoic acid, melting at 140°.
Action of reducing agents,.	Forms para - toluidine, melting at 45°.	Forms meta-toluidine, not solidifying at —20°.	Forms ortho-toluidine, not solidifying at —13°.

The various nitroxylenes and nitrocumenes have not as yet been minutely examined; the nitroxylene obtained by nitrating methyl toluene or para-xylene (p. 343) boils at 240°; that from isoxylene or meta-xylene, at 237° to 239°, and solidifies in a freezing mixture, melting at + 2 (TAWILDARROW).

Nitrocumene, from the nitration of trimethyl benzene (pseudo cumene,) boils at 265°, and melts at 71° (FITTIG); that from mesitylene boils at a temperature between 240° and 250°, and melts at 41°. The nitrocumene present in commercial nitrobenzol is probably a mixture of these two bodies, and possibly of other isomerides also.

The existence of higher homologues of nitrocumene in commercial nitrobenzol has not yet been definitely proved.

In addition to the above-mentioned mono-nitro derivatives of benzene, more highly nitrated products are often present in commercial nitrobenzol to a greater or less extent, depending much on the way in which the manufacture is carried out. The following list exhibits the chief of them:—

Dinitrobenzene, melting point 80°, ...	$C_6H_4\left\{\begin{matrix}NO_2\\NO_2\end{matrix}\right.$
Dinitrotoluene, from nitration of toluene, melting point 71°, ...	$C_6H_3\left\{\begin{matrix}CH_3\\NO_2\\NO_2\end{matrix}\right.$
Dinitroxylene, from nitration of para-xylene. Two isomeric modifications are thus formed, one melting at 123°·5, one at 93°, ... Dinitro-isoxylene, from nitration of isoxylene (metaxylene), melting point 93°, ...	$C_6H_2\left\{\begin{matrix}CH_3\\CH_3\\NO_2\\NO_2\end{matrix}\right.$
Dinitrocumene, from nitration of pseudo cumene, ... Dinitro-mesitylene, from nitration of mesitylene, melting point 86°, ...	$C_6H\left\{\begin{matrix}CH_3\\CH_3\\CH_3\\NO_2\\NO_2\end{matrix}\right.$

On reduction, the bodies give rise, first, to *nitraniline*, $C_6H_4\left\{\begin{matrix}NO_2\\NH_2\end{matrix}\right.$, and its homologues; secondly, to phenylene diamine, $C_6H_4\left\{\begin{matrix}NH_2\\NH_2\end{matrix}\right.$, and its homologues. For the description of these derivatives and the properties of their various isomerides derived from other sources, and of the further nitro derivatives of benzene and its homologues (*e.g.*, trinitrobenzene, $C_6H_3(NO_2)_3$; trinitrotrimethyl benzene, $C_6(CH_3)_3(NO_2)_3$, &c., &c.), the reader is referred to the manuals and text-books of chemistry.

Chlorobenzene, C_6H_5Cl, and its higher homologues, have been proposed by **Poulain** as a source of aniline colours (*vide* article **Aniline**); these products are obtained by the action of chlorine in presence of iodine on benzene and its homologues: on nitration, chlorobenzene is obtained from a nitrochloro chlorobenzene, from which chloraniline is obtained by the usual process of reduction; similarly with the higher homologues.

Manufacture of Nitrobenzol.—The earliest methods employed in the production of nitrobenzol were only suitable for the manufacture of small quantities at a time; as the trade increased numerous accidents occurred, partly due to the impurity of the benzol used (benzol containing carbolic acid, &c., being attacked by nitric acid with explosive violence in some cases), partly to the poisonous nature of the nitrobenzol itself, which continually leaked from the earthenware vessels employed, and partly to the injurious action on the lungs of the workmen of the nitrous fumes evolved. The use of highly concentrated nitric acid, mixed with strong sulphuric acid, instead of the more dilute acid at first employed, permitted cast-iron vessels to be substituted for earthenware ones; and the improved processes adopted for the purification of the benzol used obviated the dangers arising from explosive action and from the evolution of corrosive gases, or at least reduced these dangers to an amount quite inconsiderable with due care and suitably constructed apparatus.

Essence de mirbane was at first fabricated by allowing benzene to drop slowly into a mixture of strong sulphuric acid and of ordinary nitric acid. The acids were mixed in a vessel placed in a tub of water, much heat being evolved by adding this comparatively dilute nitric acid to the sulphuric acid; the benzene was then allowed to drop in, with occasional stirring. The difficulty of regulating the action in this arrangement was considerable, and dangerous explosions often occurred, especially when considerable quantities of materials were used. The object of adding sulphuric acid is virtually to concentrate the nitric acid by uniting with the water set free in the reaction—

$$C_6H_6 + NO_2.H = H.OH + C_6H_5.NO_2.$$

Theoretically, there should be no evolution of lower oxides of nitrogen; but secondary reactions are often set up, and the oxidation of the impurities in the benzene used also gives rise to the production of nitrous gases.

By operating in this way, the nitric acid being in excess with reference to the benzene as the latter enters, considerable quantities of dinitrobenzene are formed; hence the process is now modified in this way, that the mixture of acids is allowed to drop into the benzene instead of *vice versa*, the nitric acid used being the strongest possible, *i.e.* the red "fuming acid" of commerce (nitric acid of specific gravity 1·4 or higher, containing lower oxides of nitrogen dissolved in it).

Laroque proposed the preparation of nitrobenzol by allowing the *vapours* of benzol and nitric acid to react on each other, each substance being distilled from a separate still, the vapours meeting in a common worm tube. This process does not seem to have met with much favour; but **Mansfield**'s plan of allowing *liquid* benzol and acid to trickle together into a funnel placed at the top of a worm tube has been adopted with success, the rate of flowing of the two streams being suitably adjusted by stopcocks, so that about 3 parts of acid to 2 of benzol are allowed to mix. Instead of a worm tube, a vertical glass column filled with balls or fragments of glass has been employed, so as to effect an intimate mixture of the benzol and acid by gravitation, by using these substances in the following proportions:—

Benzol, ...	10	kilos.
Nitric acid of specific gravity 1·5, ...	12	"

Two liquids drop out at the bottom of the tube, and collect in a suitable tank placed to receive them (a ventilator or chimney being attached to the tank to allow of the escape of nitrous fumes, this chimney being cooled by a stream of water applied to its exterior, or interior, if necessary, so as to condense nitrous acid vapours should they escape). Of these liquids one is nitrobenzol, the other nitric acid of specific gravity 1·302, sufficiently strong for many industrial applications (**Girard** and **De Laire**).

The nitrous vapours evolved in the manufacture of nitrobenzol have been utilized for vitriol making; spent or dilute nitric acid, washings, &c., may be converted into nitrate of lime by saturation with chalk or marble, evaporated to dryness, and distilled with strong sulphuric acid so as to regenerate the strong nitric acid required.

Nitrate of soda, mixed with sulphuric acid, has been employed by PERKIN in lieu of nitric acid, or a mixture of nitric and sulphuric acids. The required amount of nitrate of soda is introduced into a horizontal cylinder of cast iron, furnished with a manhole covered by a luted door, and with two tubulures at the top; to the one is attached the condensing worm, through the other are introduced from time to time benzol and sulphuric acid; explosive action is very apt to occur with this arrangement.

The method now employed in the principal factories is the one first used, with the modification that the mixture of acids is made to drop into the benzene instead of *vice versa*. A cylindrical cast-iron vessel of 30 to 40 cubic feet capacity is provided with an agitator, an exit tube for nitrous vapours (cooled externally by cold water so as to condense nitric acid vapour should that escape), and a syphon S-shaped delivery tube, whereby the acid is allowed to run in from a reservoir by gravitation. The benzol to be nitrated is introduced into the cylinder, the agitator is revolved by machinery, and the mixture of acids allowed to trickle in slowly. It is sometimes necessary to warm the cylinder slightly to start the action, or to cool it to diminish the activity. This can be effected by means of a jacket surrounding the lower part of the cylinder, into which hot or cold water or steam can be let at pleasure. With a uniform system of working this jacket can be dispensed with, the action being moderated, if proceeding too violently, by cutting off the supply of acid until the action is diminished sufficiently.

Fig. 5.

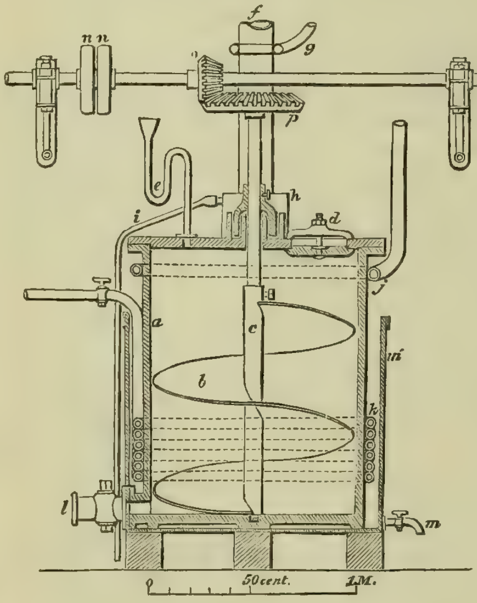
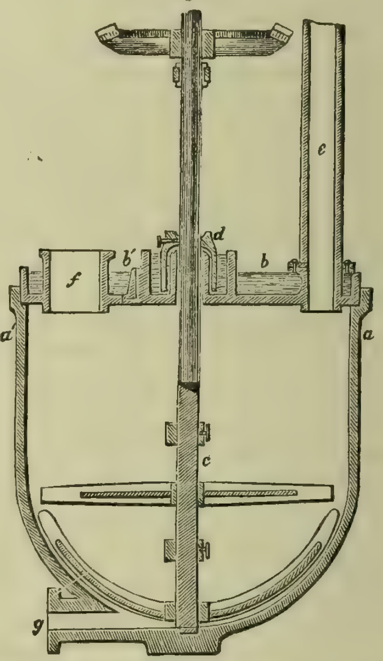


Fig. 6.



The following diagram illustrates the nature of the arrangement (GIRARD and DE LAIRE, "Traite des Derivés de la Houille," Paris, 1873). Fig. 5: *a*, cast-iron cylinder; *b*, helical agitator; *c*, axle of agitator; *d*, manhole for introduction of solid materials; *e*, syphon tube for introduction of liquid materials; *f*, escape-pipe for gaseous and vaporous products; *g*, circular water-pipe, whereby a thin sheet of water is made to flow down the exterior of the escape-pipe *f*; *h i*, reservoir and overflow pipe for descending stream of water; *j*, circular water-pipe, whereby a thin sheet of water is made to flow down the exterior of the cylinder *a*; *k*, worm tube capable of being used for steam, hot water, or cold water as required, to warm or cool the cylinder *a*; *l*, emptying cock; *m*, emptying cock, for emptying jacket *m'*; *m'*, water jacket; *n n o p*, pulleys and cog wheels for communicating motion to agitator.

Fig. 6, and BENZOL, Plate I., Fig. 2, illustrate another form of arrangement. *a* is a cylindrical vessel with hemispherical bottom made of cast iron; *b b*, dish-shaped lid holding water, whereby vapours are partially condensed; *c*, agitator spindle; *d*, water lute fixed to agitator; *e*, exit pipe for vapours; *f*, manhole for introduction of materials; *g*, emptying pipe; *m*, shaft communicating motion to agitators. Several stills are arranged side by side as indicated in Plate I., Fig. 2.

When the nitration is completed, the agitator is stopped; after standing some time the acid is run off by a tap at the bottom of the cylinder, and the nitrobenzol washed in the nitrating cylinder by introducing water, revolving the agitator, then allowing to stand, and running off the acid water, and repeating the operation. The acid being apt to attack the metal of the cylinder, &c., milk of lime or solution of caustic soda is usually employed in the first washing, water being used for the subsequent ones.

In a large factory it is better to wash all nitrobenzene at once in a separate vessel. A cast-iron tank (Fig. 7) of some 6 or 7 cubic yards capacity is so arranged at the basement, that the nitro-benzol and acids from all the nitrating cylinders can be run into it simultaneously. The tank is partially exhausted of air, so that the nitrous fumes are sucked into it along with the liquids. The acids are then drawn off by taps at the bottom of the tank, and a jet of water with which milk of lime is mixed allowed to flow in through a serpentine tube (Fig. 8), pierced with holes in such a way that a circular movement of the contents of the tank is set up together with an upward current from the bottom; the small amount of residual acid is thus immediately neutralized; the aqueous liquid is then run off, and several washings with pure water given.

Fig. 7.

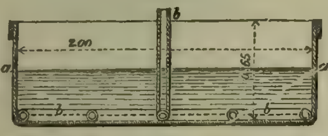
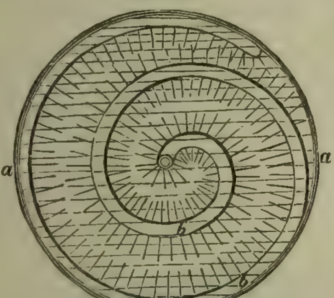


Fig. 8.



When the manufacture of the nitrobenzol has been properly carried out, the product thus obtained amounts to 135–140 per cent of the benzol used, and can be run immediately into the aniline stills. The material made by the older processes, however, frequently contained unaltered benzol, which was removed by distilling in retorts heated by a water-bath or a steam jacket. The quantity of dinitrobenzol present in well made nitrobenzol is not great; but the products of the older processes frequently required to be distilled so as to separate the more volatile aniline-producing constituents from the less volatile dinitro bodies, &c. When required (as in the preparation of *essence de mirbane*), this is now effected by blowing a jet of steam (superheated if necessary) through the nitrobenzol contained in a large still, the worm tube carrying the steam being pierced with holes, and reaching to the bottom of the still. With a copper still of 1500 to 2000 litres capacity, and steam at 5 atmospheres, 150 to 200 kilos. of nitrobenzol can be distilled per hour (GIRARD and DE LAIRE). Formerly the distillation was carried on in small retorts heated over a free fire or by hot air. As the distillate is apt to be slightly acid, it is well to add a little chalk.

The preparation of *essence de mirbane* is identical with that of the nitrobenzol of the aniline maker, except that the product is usually distilled with steam, and that nearly pure benzene is used.

The manufacture, in this way, of so-called artificial oil of almonds dates from 1847, when it was first prepared by MANSFIELD. Of late years the actual oil of bitter almonds (benzoyl hydride) has been prepared by the action of certain oxidizing agents on benzyl chloride as follows:—

Manufacture of Benzoyl Hydride, Oil of Bitter Almonds, Benzaldine, Benzoic Aldehyde (C_7H_6O):—Toluene is heated in a vessel furnished with a cohobator and a distilling worm, in such a way that either can be connected or disconnected at will. The cohobator being coupled on, the toluene is heated to the boiling point and a current of chlorine passed through the vapour emitted. This is best regulated by means of an aspirator attached to the cohobator, two WOLFFE'S bottles being interposed, the first containing water, to complete the arresting of toluene, &c., the second caustic soda ley, to retain chlorine.

If chlorine acts on *cold* toluene, chlorotoluene, $C_6H_4\left\{\begin{matrix}CH_3\\Cl\end{matrix}\right.$, chiefly results; but at the boiling temperature benzyl-chloride is formed, the two reactions being—

$$\text{(Cold.)}\quad C_6H_5.CH_3 + Cl_2 = C_6H_4\left\{\begin{matrix}CH_3\\Cl\end{matrix}\right. + HCl$$
$$\text{(Hot.)}\quad C_6H_5CH_3 + Cl_2 = C_6H_5.CH_2Cl + HCl$$

The two products, though possessing the same percentage composition, are wholly different, physically and chemically; thus, their boiling points are 20° C. apart, and the former is incapable of forming artificial oil of almonds.

When a thermometer indicates that the liquid in the still boils at 140° to 145° the chlorine current is discontinued, the cohobator disconnected, and the contents of the still distilled over. The portion boiling below 170° is chiefly unaltered toluene, and is used over again; that which passes at 170° to 200° is rectified, and the portion boiling at 174° to 176° collected apart.

Instead of benzyl chloride, benzyl bromide may be used. This is prepared in just the same way, save that bromine vapour is used instead of chlorine gas, the portion collected during the final rectification being that passing at 195° to 205°.

LAUTH and GRIMAUX convert benzyl chloride into benzoyl hydride thus; 1¼ kilo. of lead acetate, 10 litres of water, and 1 kilo. of benzyl chloride, are heated together in a cohobator from three to four hours, a current of carbon dioxide being passed through the apparatus (to displace air, the oxygen of which would convert the bitter almond oil into benzoic acid). The contents of the retort are then half distilled over; the whole of the benzoyl hydride then passes along with water, on which it floats; the oily liquid is decanted and heated with sodium acid sulphite, with which it combines; the crystalline compound is washed with alcohol and decomposed by addition of an alkali. The yield is about three quarters of the theoretical amount.

BISMUTH.—*Etain de Glace*, French; *Wismuth*, German: symbol, Bi; atomic weight, 208 (SCHNEIDER), 210 (DUMAS).—This comparatively rare metal has been known for about three centuries, GEORGE AGRICOLA having described it in 1546 as a metal "somewhat different from lead." In nature, bismuth occurs principally in the metallic state, generally associated with the ores of cobalt, nickel, copper, and silver; and in combination as *Bismuth glance* or *bismuthine*, Bi_2S_3; *bismuth ochre*, Bi_2O_3; *bismuthite*, Bi_23CO_3; *bismuth blende*, Bi_23SiO_3; *cupreous bismuth*, $3(Cu_2S)Bi_2S_3$; and combined with copper, silver, lead, cobalt, and nickel, in several other more complex minerals, among which may be mentioned *aciculite* or *needle ore*, *kobellite*, and *bismuthic silver*. It is found with tellurium in *tetradymite*, and with vanadium in *pucherite*.

Bismuth ores occur most plentifully in Saxony, Bohemia, and Transylvania; but they are also found in Norway, Sweden, and the United States, and in England in Cornwall and Cumberland, and Stirlingshire in Scotland.

Metallurgy.—Bismuth is almost wholly obtained from ores containing the native metal, its extraction from which is rendered exceedingly simple by its ready fusibility. The ancient method was to fire a mixture of ore and fuel, when the metal melted and subsided to the bottom of the heap. At Schneeberg, in Saxony, where the greater part of the bismuth in the market is produced, it is obtained from cobalt ores previously to their employment in the manufacture of smalt.

The operation is conducted in cast-iron retorts placed obliquely, and heated by a furnace beneath them. When the bismuth of the ore with which these retorts are charged is fused, it flows down into an appropriate receiver, leaving behind it the siliceous and other impurities. The furnace used at Schneeberg is represented in the annexed Figs. 1, 2, 3; the first of which is a plan; the second a section at A B, Fig. 1; and the third a front elevation at *k k*, Fig. 1. In the plan—Fig. 1—the fire-door is represented by *a*, the grate by *b*, and the cylindrical retorts by *c c c*, which incline towards the iron pans, *i i i*, where the fused metal is collected. A wall, *k k*, supports the pans; and to prevent the metal from forming an alloy with the latter, and also to obviate its oxidation, it is customary to throw a little charcoal powder into each. The slag remaining in the pipes after the metal is separated from it, is drawn off into a tank of cold water situated at *m*. In doing this the heated matter does not splash at once into the water, but falls gently down the declivity, *h*. This arrangement is shown in elevation—Fig. 2—which is a section of the preceding, the same objects being distinguished by the foregoing letters. The pipes, *c c*, are closed at the depressed end by clay plates, *f*, with the exception of a small opening through which the fused metal issues to the receivers, *c*. A stout cast-iron door-plate, *l*, secures them at the other end. The retorts are heated by the fire, *e*, with the assistance of flues passing from it round each severally, as seen in Fig. 2 and Fig. 3, at *g g*. The draught of the furnace is increased at will by opening the holes shown at *n n*, Fig. 2, placed between each pair of retorts.

Fig. 1.

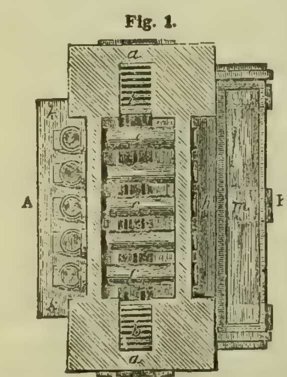
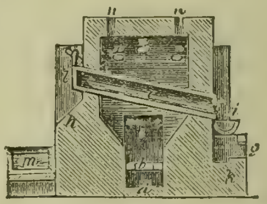
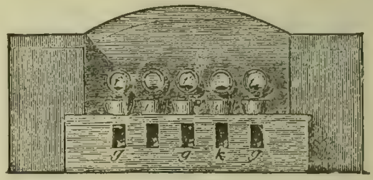


Fig. 2.



The ore is prepared by breaking it up and removing the very impure portions; this being effected, about half a hundredweight is introduced into each of the retorts, the door-plates, *l*, made secure, and the fire stirred up to communicate the required degree of heat. The charge should only be about three-eighths of the capacity of the retorts, in order that it may be conveniently stirred. After the application of the heat for ten minutes the metal begins to run out by the small space in the clay plate, *f*, at the end; and as soon as the flow slackens the contents of the retort are stirred with a rake till the whole of the metal is obtained, which is usually the case in half an hour. The slag, deprived of all the metal, is then raked out of the retorts into the water tank in front, and replaced by a fresh charge. When the pans, *i i i*, are nearly full, the fused metal is ladled out and cast into bars, weighing each from 20 to 50 lbs.

Fig. 3.



At Schneeberg, where about 10,000 pounds of bismuth are annually produced, wood is the fuel employed, 50 cubic feet of which is sufficient to work off a ton of ore.

At Joachimsthal, in Bohemia, a process devised by VOGEL, for extracting bismuth from other ores than those containing the native metal, has latterly been employed. The ore is powdered, mixed with 28 per cent. of small scrap iron, 15 to 50 per cent. of soda ash (according to the amount of silica in the ore), 5 per cent. of lime, and 5 per cent. of fluor spar. Crucibles, 2 feet in height and 16 inches in diameter, are each charged with about 1 cwt. of this mixture, closed, and strongly heated till the mass becomes pasty. The contents are then well stirred to effect complete mixture, reheated till perfectly liquid, and then ladled into conical moulds. The bismuth, together with the cobalt speiss, subsides to the bottom, and on cooling is separated from the speiss, which, however, still retains about 2 per cent. of bismuth.

Refining.—The bismuth obtained by these methods is contaminated with arsenic, iron, copper, and silver.

The greater part of the arsenic may be removed by strongly heating the bismuth in a crucible under a layer of charcoal, when the arsenic passes off in vapour. TAMM recommends immersing strips of iron in bismuth fused under a layer of borax. He states that the arsenic unites with the iron, and on cooling the still fluid bismuth may be decanted from the iron arsenide, which solidifies more rapidly.

Copper, according to the same authority, may be removed by treating the fused metal with one-sixteenth part of a mixture of 8 parts potassium cyanide, with 3 parts of sulphur, the crucible being kept covered during the deflagration that ensues. The metal is then well stirred and the flux allowed to set, upon which the metal is poured out.

Antimony may be removed by heating the bismuth with about 3 parts of teroxide of bismuth for each part of antimony present, the antimony being converted into oxide, while the oxide of bismuth is at the same time reduced to the metallic state.

Bismuth, when required pure, may be prepared by dissolving ordinary bismuth in just sufficient nitric acid, filtering from arseniate of bismuth and other insoluble impurities, and then largely diluting with water, which precipitates the bismuth as basic nitrate. This precipitate is washed and digested with potash, after which it is again washed, and finally reduced to the metallic state by heating with charcoal in a crucible.

Properties.—Bismuth is a white metal with a tinge of red. It crystallizes in rhombohedra closely resembling cubes, which are obtained artificially in the following manner:—A large quantity of bismuth is fused in a crucible; while still red hot the crucible is embedded in hot sand, so as to cool slowly. When part of the metal has solidified and there is a firm crust on the surface, two holes are made in the crust with a red-hot rod, and through one of them the metal still remaining liquid is poured off; the other hole serves to admit air. Upon breaking the crust the solidified portion will be found beautifully crystallized, the crystals having an iridescent tarnish, caused by contact with the air while yet hot. Bismuth is exceedingly brittle, and it has so little tenacity that a rod one-tenth of an inch in diameter only sustains 40 lbs.

Pure bismuth melts at 264° C. (607° Fahr.); at a high temperature it volatilizes, and may, though with great difficulty, be distilled. Its specific gravity is variously given at from 9·6 to 9·8, the higher number being probably the more correct. When subjected to pressure, instead of being rendered denser, it is reduced in specific gravity. Thus MARCHAND and SCHEERER, by submitting a cylinder of the metal to powerful pressure, succeeded in reducing its specific gravity from 9·799 to 9·556. It is the most diamagnetic substance known. Its diamagnetic repulsion being nevertheless only $\frac{1}{2300000}$ of the attraction of an equal mass of iron.—(WEBER.)

Bismuth, like water, expands on solidification; but while water expands on cooling from 4° C. to the freezing point, bismuth only expands at the moment of solidification.—(TRIBE.) When fused it can be cooled several degrees below its melting point without solidifying, but the instant that solidification begins, the temperature rises to the fusing point, and remains so till the whole has solidified.—(URE.)

Bismuth is not affected by dry air, and is only slightly acted on by a moist atmosphere; its vapour decomposes steam (REGNAULT), and the solid metal at a white heat decomposes water. When strongly heated in the air, it burns with a bluish flame, evolving light yellow fumes of bismuthous oxide, Bi_2O_3. In chlorine gas, divided bismuth takes fire, forming bismuthous chloride, $BiCl_3$. It is attacked with difficulty by hydrochloric and sulphuric acids, but is readily dissolved by slightly dilute nitric or nitrohydrochloric acids, forming bismuthous nitrate and chloride respectively. It also enters into combination with most of the non-metallic elements, and with many inorganic negative radicles.

Uses in the Arts.—Bismuth is too brittle to be useful by itself, and hence is chiefly employed in the arts for alloying with other metals, generally lead and tin, in order to communicate to the resulting alloy, either fusibility or the property of expansion on solidification above referred to. In bell-founding, bismuth is of considerable value, its alloy with tin being very sonorous.

Bismuth is sometimes employed in stereotype metal to communicate its expansive property, which causes the alloy to take a very exact impression, and for the same reason it is used by die sinkers in the fusible metal employed to test the accuracy and finish of a die.

Fusible metal is an alloy of bismuth, tin, and lead. Thus, an alloy of 8 parts bismuth, 5 of lead, and 3 of tin melts at 202° Fahr.; and another, consisting of 2 parts bismuth, 1 of lead, and 1 of tin, liquefies at 200°·75 Fahr.—(ROSE.) Both these alloys are liquid in boiling water.

These fusible metals are rendered still more fusible by the addition of small quantities of mercury; such alloys are serviceable for taking casts of anatomical preparations.

The soft solder employed by pewterers consists of 1 part bismuth, 2 of tin, and 1 of lead; and the same composition has been proposed as a bath for tempering steel instruments, and has also been used in making the cake moulds for fancy toilet soaps.

An alloy for electrotype moulds is composed of 8 parts bismuth, 8 lead, and 3 tin. It melts at 228° Fahr. It is allowed to cool till it acquires a pasty consistency, and the warmed medal, or other article, pressed upon it and kept under pressure till cold.

If 2 parts of hot mercury be added to 1 part of fused bismuth, a pasty amalgam is obtained, which after a time becomes granular, hard, and partly crystalline. Since a small quantity of bismuth only slightly diminishes the fluidity of mercury, it is occasionally used to adulterate the latter. This fraud may be detected by shaking the mercury with air, when a black powder separates.—(GMELIN.)

Bismuth and silver, when fused together in equal proportions, form a bismuth-coloured alloy. The silver may be extracted by cupellation, in the same manner as from argentiferous lead. Gold may also be extracted from its alloy with bismuth by cupellation.

Platinum and also palladium readily alloy with bismuth; 1 part of platinum or 2 parts of palladium form severally with 2 parts of bismuth, grey, brittle, fusible alloys.

Bismuth when alloyed with copper renders the copper harder, but at the same time brittle: 4 parts of bismuth and 1 of copper form an alloy having the red colour of copper and the crystalline texture of bismuth.

If a small quantity of bismuth be added to lead, it makes the latter tougher without becoming brittle. Equal weights of each give an alloy which resembles bismuth in all its properties, being of red tint, brittle, and laminar.

Oxides.—Four oxides are known, viz.:—The dioxide, Bi_2O_2; bismuthous oxide, or the trioxide, Bi_2O_3; tetroxide, Bi_2O_4; and bismuthic oxide, or the pentoxide, Bi_2O_5.

Bismuthous oxide, or the trioxide (Bi_2O_3) is the most important of these, and the only one which has received any industrial application. It occurs in nature as bismuth-ochre, associated with oxide of iron, carbonic acid, and water, at Schneeberg and Joachimsthal, and with gold in Siberia. It may be readily prepared by heating the neutral or basic nitrate until nitric fumes cease to be evolved. When pure, this oxide is of a straw yellow colour; at a red heat it fuses to an opaque glass, which, while hot, is dark brown or black, but on cooling again becomes yellow. In the arts it is used for fixing the gilding on porcelains, since at a high temperature it acts as a powerful flux towards siliceous matters. It is also employed to destroy the colours which would be given by many substances used as fluxes.

Hydrated bismuthous oxide (Bi_2O_3,H_2O) forms as a white precipitate, when an alkali is mixed with a solution of any bismuthous salt, and as a white powder, when the basic nitrate or chloride is triturated with an alkali. When boiled with potash, it is converted into the yellow oxide through loss of its water of hydration. Heated with an alkaline solution of metallic sulphides, it converts them into the corresponding oxides.

The oxide and hydrate when treated with acids form bismuthous salts, of the general formula Bi_2R_3, R being univalent.

Bismuthous salts, with the exception of the yellow chromate, are white or colourless; most of those which contain oxygen are non-volatile, and decompose at a red heat. The chloride is, however, volatile. The neutral salts redden litmus paper, and are decomposed by a large quantity of water.

Nitrates.—Ternitrate, $Bi(NO_3)_3,5H_2O$. To prepare this salt the metal is dissolved in nitric acid with the aid of heat, and the solution concentrated by evaporation; on cooling it deposits in deliquescent transparent prisms. The crystals dissolve easily in dilute nitric acid, and on mixing this solution with water an insoluble basic nitrate precipitates, an acid salt remaining in solution.

Basic Nitrate or Trinitrate of Bismuth (*Bismuthum Album*, *Magistery of Bismuth*, *Flake White*). This compound is formed in the manner just mentioned, but to obtain the maximum yield, it is recommended to add 24 parts of hot water for each part of ternitrate; by this treatment 45 per cent. of the basic nitrate is obtained. Too much water should not be used in washing the precipitate, as it is rendered more basic by this treatment. The filtered liquid from the precipitate may be evaporated to dryness, or nearly so, and again decomposed by addition of water, when a further quantity of the basic salt is obtained. The washings from the first precipitation may be used for decomposing this second quantity. The purified metal must be used in the first instance if a pure product be desired, since the subnitrate is liable to contain arsenic and other impurities if this precaution be not taken.

Basic nitrate of bismuth thus obtained is a pearly white powder of a loose texture, presenting the appearance of crystalline scales under the microscope. Prepared from acid solutions with but little water it has a silky lustre, and the crystals are acicular. The salt manifests an acid reaction with litmus. It varies to some extent in composition, according to the temperature and the quantity of the water employed in its preparation, but it agrees pretty closely with the formula $Bi(NO_3)_3,Bi_2O_3,3H_2O$.

Oxychloride of bismuth may be prepared by adding water to a solution of the chloride, or by pouring a solution of ternitrate into a solution of common salt. It is used as a paint, and is known as *pearl white*.

Basic nitrate of bismuth has been advantageously employed in medicine. It is administered principally in affections of the stomach which are unaccompanied by any organic disease. It has been particularly prescribed to relieve gastrodynia and cramp of the stomach, to allay sickness and vomiting, and as a cure for pyrosis. Dr. PEREIRA gave it in the form of powder in conjunction with hydrocyanic acid mixture, and remarked that the patient seldom failed to obtain benefit from its use. Dr. THEOPHILUS THOMSON recommends it in doses of 5 grains, usually combined with 3 of gum arabic and 2 of magnesia, given every four or six hours in the diarrhœa accompanying phthisis. He thinks that both for efficacy and safety it surpasses our most approved remedies for that complaint. It has also been administered in intermittent fever and spasmodic asthma. HAHNEMANN directed a portion of it to be introduced into a hollow tooth to allay toothache. It was also used with advantage by Dr. PEREIRA, in the form of ointment applied to the *septum nasi* in ulceration of that part, and as a local remedy in chronic skin diseases.

In small doses it acts as an astringent, diminishing the secretion; but in large doses it is undoubtedly poisonous. It disorders the digestive organs, causing pain, vomiting, and purging, sometimes affecting the nervous system, producing giddiness, insensibility, cramp of the extremities, and even death.

Upon the lower animals it acts as a local irritant and caustic poison, and appears to exercise a specific influence over the lungs and nervous system.

It was formerly extensively employed as a cosmetic; but even here its use is dangerous, since when thus employed it produces spasmodic trembling of the face, commonly ending in paralysis.

Detection and Estimation.—Bismuth in solution is thus characterized:—

Sulphuretted hydrogen, in slightly acid or in alkaline solutions, throws down the black tersulphide.

Alkalies precipitate white bismuthous hydrate, insoluble in excess of the precipitant.

Potassium chromate throws down the yellow chromate, soluble in nitric acid and insoluble in potash.

Soluble sulphates produce no precipitate, which fact, in conjunction with the insolubility of the hydrate and chromate in potash, distinguishes bismuth from lead.

Water throws down a white basic salt in solutions of the chloride and nitrate, unless a large quantity of free acid be present. Where such is the case, or where the solution is very dilute, it is evaporated nearly to dryness previously to the addition of water; and if sulphuric acid be present, some sodium or ammonium chloride should be added. The basic salt being insoluble in tartaric acid, distinguishes it from antimony. This reaction with water is very characteristic. Before the blow-pipe, bismuth, with reducing agents on charcoal, gives a brittle metallic bead and a yellow incrustation.

Estimation.—When bismuth has to be estimated in those of its compounds which are free from admixture with other metals, the body is brought into the state of nitrate by acting on it with nitric acid, diluting the solution with water, heating almost to ebullition, and precipitating with carbonate of ammonia. In presence of hydrochloric acid the precipitate thus produced would contain some oxychloride, which on ignition would decompose, and part of the bismuth volatilize as chloride. In such a case the bismuth is first precipitated from the acid solution with sulphuretted hydrogen, and the tersulphide washed, removed while moist, together with the filter, to a beaker glass, and converted into nitrate by means of nitric acid. The end of the decomposition is indicated by the separated sulphur assuming a yellow colour. The remains of the filter paper are then filtered off, after addition of dilute nitric acid, and the filter well washed. The filtrate and washings are then mixed, and the bismuth precipitated with ammonium carbonate, the solution being heated as above mentioned. The precipitate is to be collected in a filter, washed with water, dried, transferred as much as possible from the paper to a porcelain crucible, and ignited. The filter is then burned separately, and the ash added to the oxide in the crucible and weighed. If highly ignited the oxide fuses, but does not decompose. As the teroxide contains 89·6 per cent. of metal, the amount of bismuth may easily be calculated. Bismuth being usually found associated with other metals—generally lead, silver, copper, arsenic, and iron—it may be interesting to give the process whereby the quantity of bismuth is ascertained in mixtures of these metals. The method also serves to detect adulteration in the preparations of bismuth, particularly when compounds of those metals are used.

The ore or compound is treated with nitric acid till dissolved, and this solution filtered and diluted with water; the washings of the residue, if any, are added, and a stream of sulphuretted hydrogen passed through it as long as a precipitate is produced. The vessel is then gently heated upon the sand-bath till the whole of the sulphides fall down; these are filtered and washed with water impregnated with sulphuretted hydrogen. The substance upon the paper is next digested with a strong solution of sulphide of potassium, which dissolves the sulphide of arsenic, leaving the sulphides of lead, silver, copper, and bismuth, which are separated from this solution by filtration and washing. These sulphides are then dissolved in nitric acid, the solution thus produced largely diluted, and the silver precipitated by hydrochloric acid. When the silver chloride has subsided, it is filtered, and the filtrate and washings evaporated with excess of sulphuric acid till the latter begins to be evolved. Sulphate of lead is thus formed, which is removed by filtering rapidly while hot, and washing the precipitate with water acidulated with sulphuric acid. The filtered solution now contains copper and bismuth. To separate the latter mix the diluted solution with carbonate of soda, in slight excess, add solution of cyanide of potassium, heat gently for some time, filter, and wash. The compound of bismuth on the filter contains some alkali, to remove which it is dissolved in nitric acid and reprecipitated by ammonium carbonate, as above directed. The precipitated bismuth is then treated in the same manner as before.

The quantity of each of the other constituents may be ascertained by weighing the precipitates already procured in the case of lead or silver. By adding ammonia to the filtrate containing the iron this body is thrown down as sesquioxide, which may be collected, dried, ignited, and weighed. The copper in solution, after the precipitation of bismuth, is ascertained by evaporation with strong sulphuric acid, to decompose the cuprocyanide of potassium, after which the copper may be thrown down by addition of caustic potash in excess and boiling. The black precipitate, consisting of oxide of copper, is well washed with boiling water, dried, separated from the filter, ignited, and weighed. This gives the amount of oxide of copper.

BITUMEN.—Asphalt, Mineral Pitch.—*Bitume*, *Asphalte*, French; *Bergpech*, *Erdpech*, German; *Asphaltum*, Latin.—Bitumen is a name used to denote various inflammable substances, consisting for the most part of hydrocarbon, of a strong smell and of different consistences, which are found in the earth.

There are several varieties, most of which pass into each other, proceeding from naphtha, the most fluid, to asphalt, which is sometimes too hard to be scratched by the nail. The most important forms are:—

Naphtha, or rock oil, a colourless liquid of the specific gravity 0·7 to 0·8.

Petroleum, a dark coloured liquid containing much naphtha.

Mineral tar, or *Maltha*, a viscous fluid.

Asphalt, a black or brown black brittle resinous substance, breaking with a smooth conchoidal fracture. Besides these there are various forms of mineral ozocerite, or ozokerit, Urpethite from the Urpeth colliery, and Hatchettite from Merthyr Tydville, which are various forms of mineral tallow.

Extensive magazines of bitumen are found in many parts of the world. It is sometimes found on the surface, exuding from the secondary or alluvial strata, where it is generally met with; but it is never found in the primary or older formation. The manner in which natural bitumen was formed is unknown, but it is supposed to be the result of the action of heat and moisture on organic substances which have been buried in the earth at a bygone period. This heat, when exerted upon such matters out of contact with air, would, as is well known in the laboratory, effect a decomposition analogous to destructive distillation, but different, inasmuch as that the pressure exerted at the same time would effect the liquefaction or solidification of many of the gaseous products evolved in the process. It is believed that a great deal of bitumen is formed from coal or lignite. Sulphuric acid by the aid of heat decomposes organic bodies, and gives rise to compounds, often bituminous, and very similar to the natural product.

The largest bituminous deposits in the world are those of the Dead Sea in Judea, and the Pitch or Tar Lake in Trinidad. Besides these extensive formations, bitumen is found in many other parts of the world; namely, as *mineral oil*, in Persia, the Caucasus, Burmah, the West Indies, and North America. And in smaller quantities in Italy, Bavaria, Hanover, China, and India. As asphalt and its congeners bitumen is met with in considerable quantities at Hatten, Bechelbronn, and Lobsann in Alsace, on the Lower Rhine; in France, at Parc and Pyrimont, near Seyssel on the Rhone, in the department of Ain; at Bastennes and Dax, department of Landes; in the departments of Auvergne, North, and at Val de Travers, Neufchatel, impregnating a bed in the cretaceous formation, and serving as a cement to the rock, which is used for building and paving, &c. Considerable quantities are found in South America, particularly at Coxitambo in Peru; in the islands of Cuba, Barbadoes, and in many parts of the West Indies; it is likewise found in Albania; near Naples, in Italy; in Persia, and in various other parts of the world.

In England very little bitumen, comparatively speaking, has been met with. It is produced at the coal mines of Hurlet near Paisley, where it incloses crystals of calcareous spar, and at the Odin mines in Derbyshire. The peat cut on Downholland Moss, near Ormskirk, Lancashire, has been found strongly impregnated with it. Considerable quantities of bituminous limestone are found in East Lothian, in Scotland.

These deposits are more fully described in the article Petroleum. The fluid and colourless kinds of bitumen are called naphthas, from the oriental word *nafata*, signifying to exude or pour out, as this curious liquid does, into the water of pits worked on the shores of the Caspian Sea. Viscid petroleum, or rock oil, seems to be liquefied asphalt, the solution being naphtha, or some analogous hydrocarbon. Petroleum chiefly flows from beds associated with coal strata. Until recently the Burman empire furnished the largest quantity of crude naphtha, but of late years the oil from the Pennsylvanian wells has almost entirely replaced Burmese petroleum.

A sandy loam, deposited upon alternate layers of siliceous and argillaceous matter, resting upon a bed of coal, are the geological characteristics of the district in which petroleum is met with. The clayey bed in contact with the strata of coal, which is of a bluish colour, contains the volatile fluid; and by sinking a shaft to some depth in this strata, the fluid, or rock oil, as it is termed, flows into it with sometimes no admixture of water.

Petroleum is also obtained in considerable quantity from the district of Baku, near the Caspian Sea. This locality is famed for its inextinguishable fires, which have continued burning for ages. They are occasioned by the ignition of the inflammable vapour exhaled from the soil, which is surcharged with the naphtha.

The bitumen of the Dead Sea, and that of the Tar Lake of Trinidad, as well as the viscid varieties of this country, and of many other parts, such as those of Bechelbronn in Alsace, &c., are apparently produced by the oxidation of liquid petroleum.

Naphtha, or fluid petroleum, is produced during the distillation of bituminous matters. Large quantities are obtained in the distillation of coal, and in the manufacture of pyroligneous acid.

Naphtha does not combine with water, but imparts a peculiar smell and taste to it. With strong alcohol, ether, and essential oils, it unites in all proportions. It dissolves sulphur, phosphorus, iodine, camphor, most of the resins, wax, and fats, as also caoutchouc, which it converts into a varnish. Ordinary pitch gives, upon distillation, a light liquid like natural naphtha; but, according to Mansfield, they are not identical, for the former, as has been shown by this chemist, Hofmann, and others, is a compound of many volatile liquid hydrocarbons, which are not found in the latter.

Naphtha has been applied to several important uses in the arts. It is of great value for out-door illumination, for which it is employed very extensively; it is also much used as a solvent for caoutchouc in the preparation of varnishes. When incorporated with soap it is said to deprive that detergent of its causticity, which reacts with great irritation upon delicate skins.

Solid bitumen is of three distinct kinds—namely, the earthy, the elastic, and the compact; the latter is termed asphalt. Earthy bitumens have a brownish-black, dull colour, with an earthy, uneven fracture, and soft enough to take an impression of the nail; they burn with a clear, brisk flame, emitting a powerful odour, and depositing much soot. Elastic bitumen is of various shades of brown; it is soft, flexible, and elastic; it has an odour strongly bituminous, and is of about the density of water; it burns with a clear flame and much smoke; by a gentle heat it may be converted into a substance resembling petroleum or asphalt, according to its previous consistence. Like caoutchouc it takes up the tracings of pencils, and on this account it is called *mineral caoutchouc*.

ASPHALT.—*Compact Bitumen*, *Mineral Pitch*; *Bitumen Judaicum*, Latin; *Erdpech*, *Bergpech*, German; *Goudron Minéral*, French.—Compact bitumen or asphalt is, as instanced above, extensively disseminated. It is of various degrees of quality, according to the quantity of impurities which accompanies it; but by simple operations the several species may be reduced to a state of equal purity, and the asphalt then possesses nearly the same properties from whatever bed or country it is obtained. Asphalt has a density less than water; but in consequence of the ingredients mixed with it, the gravity, when of the purest kind, is not less than 1·0 to 1·16, and frequently it is as high as 1·6. It has a black or brownish colour, a resinous appearance, a conchoidal fracture, and when rubbed a slightly bituminous odour; it is opaque, brittle, and does not soil the fingers. The method generally adopted for purifying the natural asphalts is by boiling or macerating them with hot water, according to the freedom with which they part with the earthy and siliceous matters in suspension. During the action of the water the sand and other ingredients fall to the bottom of the vessel, and the bitumen rises to the surface, or forms clots on the sides of the boiler, whence it is skimmed off and thrown into a large cooler, where more water separates. To purify the bitumen thus obtained more completely, it is thrown into a conical-shaped caldron, and boiled for some time, during which the water and volatile matters accompanying it fly off, and the sand and other mineral substances fall to the bottom of the boiler, leaving the asphalt in the form of a thick fatty pitch, in which state it is sent to market, or applied to the various uses which it is made to serve. Such is the method followed at the Seyssel and Bechelbronn deposits, and in various other places. In the former of these, which is the most celebrated, there are three beds of bituminous matter; the first is sandy; the second calcareous and very fusible; and the third calcareous, and not easily fused.

The Bechelbronn variety appears in the form of a bituminous sandy deposit, between two layers of clay; the working of the veins in both places is carried on by shafts and galleries.

The bituminous schist lying near a stratum of lignite at Lobsann, when acted upon by boiling water, manifests a difference in its nature from those mentioned, as the bitumen from it does not enter into fusion like the others, but rises as scum to the surface, from which it is removed by skimmers in the usual way, and remelted at a higher temperature for the purpose of driving off water and separating the sand, which is done by decanting the bitumen after the impurities have subsided. The clayey and siliceous residue is used to manufacture gas, and the bitumen employed for common asphalting.

At ordinary temperatures the asphalts of Seyssel and Lobsann are very tenacious, and in cold weather they become completely solid; the Payta deposits, those of Magdalena and Trinity island, yield similar bitumens. The Bechelbronn bitumen is viscous, and of a brown colour. It is applied for many useful purposes, particularly as a substitute for grease to lessen the friction of machinery, and also for greasing the wheels of carriages. From being applicable to these and similar uses, it has been called mineral fat, Stein oil, Strasbourg grease, &c.

Little was known of these bodies previous to the researches of BOUSSINGAULT, EBELMEN, BERTIER, and others; but by the labours of these chemists, especially the first two, their nature and composition are now pretty well understood. BOUSSINGAULT found that on submitting the asphalts or bitumens of Seyssel and Bechelbronn to distillation, they yielded more or less of a pale yellow oily liquid, which he named *petrolene*, on account of its being always an essential ingredient of petroleum. When those bitumens are heated to 212° nothing passed over, showing that they contain no naphtha; but on raising the heat to about 450° Fahr. the oil was disengaged. According to this chemist, this oil when pure is of a light yellow colour, possesses a bituminous odour, and has but little taste; it boils at 536° Fahr. (280° C.), giving a vapour of the density 9·415.

The specific gravity of petrolene at 69°·8 Fahr. (21° C.) is 0·891. It burns with a very sooty flame, dissolves very sparingly in alcohol, but ether takes it up in greater abundance. Its composition may be represented by $C_{20}H_{32}$. It contains, according to BOUSSINGAULT, 87·2 per cent. of carbon, 12·1 per cent. hydrogen.

By treating the petroleum—viscid bitumen—of Bechelbronn with alcohol it assumes great consistency, and the spirit becomes charged with the petrolene; but it cannot be wholly removed by this solvent even when submitted to distillation, for as the alcohol loses its fluidity by uniting with portions of the matter, it also loses its solvent action in proportion.

The best way to proceed is to keep the mixture at a temperature of about 482° Fahr. (250° C.) by means of an oil-bath, till it no longer loses weight. By this means the petrolene is entirely separated, and a solid body remains, which is black, very brilliant, has a greater density than water, and breaks with a conchoidal fracture; it burns like resins in general, leaving a very abundant coke. As this body possesses all the characters of asphalt, and forms the essential part of that bitumen, BOUSSINGAULT named it *asphaltene.* It gave, upon analysis,—carbon, 74·2; hydrogen, 9·9—from which BOUSSINGAULT derived the formula, $C_{80}H_{32}O_3$. GERHARD prefers the formula $C_{20}H_{30}O_9$, and considers that asphaltene is produced by the oxidation of petrolene.

The following table shows the composition of a few of the bitumens:—

	Carbon. Per Cent.	Hydrogen. Per Cent.	Oxygen. Per Cent.	Nitrogen. Per Cent.
Viscous bitumen of Bechelbronn,	88·0	12·0	—	—
Virgin bitumen of "	88·0	11·0	—	1·0
Liquid bitumen from Hatten, Lower Rhine,	88·0	11·6	—	0·4
Solid bitumen of Coxitambo, near Cuença, in Peru,	88·7	9·7	1·6	

Annexed is a table of the analysis of several asphalts:—

Centesimally represented.

	Bitumen of Bastennes.	Bitumen of Pont de Chateau, Auvergne.		Bitumen of Abruzzi.		Bitumen of Monastier, Haute Loire.
		Crude	Pure.	Crude.	Pure.	
Oily matters, Bitumen	20·0	—	—	—	—	7·0
Carbon,	3·7	76·13	77·5	77·64	81·8	3·5
Hydrogen,	—	9·41	9·6	7·86	8·4	—
Nitrogen,	—	12 66	12·4	1·02	1·0	—
Oxygen,	—		0·5	8·35	8·8	—
Water,	—	—	—	—	—	4·5
Gas and vapor,	—	—	—	—	—	4·0
Quartz sand and mica,	76·3	—	—	—	—	60·0
Clay,		—	—	—	—	Ferrug. 21·0
Ashes,	—	1·80	—	5·13	—	—
	100·0	100·00	100·0	100·00	100·0	100·0

Bitumen of Bastennes much resembles the sandstone variety of Seyssel, but it is much richer; it is compact and homogeneous in appearance, and of a dull brown colour. Although it is solid at ordinary temperatures, yet it softens in the hand, and therefore cannot be pulverized. Boiling water separates bituminous matter only in very small portions, but ether and spirit of turpentine freely remove the whole of the bitumen. Alcohol has little effect upon it in the cold, and dissolves only very small quantities at a boiling temperature. This bitumen is used in the proportion of 8 or 10 per cent. with the Seyssel asphalt in making mastic.

The asphalt of the Pont de Chateau is solid, but likewise softens in the hand, and melts completely at a moderately high heat. It has a conchoidal fracture and a fine black colour; its density is 1·068 at 53°·6 Fahr. (12° C.). It dissolves almost completely in turpentine, but only partially when treated with ether. If it be thrown upon the fire, it burns with a crackling noise, and scintillates, on account of the evolution of water; when, however, it is heated in a glass tube gradually, it intumesces, and parts with its water without any decrepitation.

Asphalt of Abruzzi is solid, very brittle, has a conchoidal fracture, and shines like jet. Ether scarcely attacks it, but it is largely dissolved in essence of turpentine. At 55°·4 Fahr. (13° C.) it has a density of 1·175; it begins to soften at 212° Fahr. (100° C.), and fuses completely at 284° Fahr. (128°·8 C.) without losing water.

Three kinds of bituminous mineral have been discovered at Monastier, in Haute Loire, which considerably differ from those above mentioned, inasmuch as they are not in the least acted upon by boiling water; and neither agglutinate nor soften when ignited, but burn with a vivid flame, leaving a dark-brown ash.

Ether and oil of turpentine readily attack these bitumens, yielding deep red-brown liquors, but do not completely dissolve them; alcohol abstracts rather more bitumen from them than ether and oil of turpentine. When distilled, they evolve oils and much water.

Bitumen of Cuba is largely imported into Europe, and passes by the name of asphalt of Mexico, or Chapopota. It comes in reality from the environs of Havannah, in the island of Cuba, where it exists in abundance. DUMAS, speaking of this bitumen, says it is solid, very brittle, conchoidal with a large fracture, and of a very fine black; but its powder takes a brown tint; it exhales a very strong though not unpleasant odour. Grains of quartz sand may be distinguished in it here and there, and also particles of wood and straw. Its density differs little from that of water; some pieces swim in that liquid, and others sink to the bottom. It softens at a moderately elevated temperature, and melts completely in boiling water into a thick liquor, which rises and floats upon the surface in the form of a scum or pellicle. Acids and alkalies leave it intact. Alcohol dissolves a small portion of it, and the solution afterwards becomes milky upon the addition of water. Ether and oil of turpentine abstract half its weight, leaving a granular black substance, fusible at a temperature above 212° Fahr. (100° C.). The ethereal extracts have a deep red hue, and when they are evaporated, the bituminous matter remains soft and transparent, and of the same colour. When calcined in close vessels, it swells up and leaves about 0·10 per cent. of a brilliant and extremely light coke. The oils which separate from it are brown and viscous.

Considerable quantities of bitumen are imported from the Dead Sea, in Judea, on the shores of which it is thrown up and collected; hence its commercial name is Jewish bitumen. This variety has a density of 1·16; it resembles ordinary pitch in colour and fracture. Boiling water melts it; and when distilled it yields a peculiar bituminous oil, some water, and traces of ammonia. It leaves about one-third of its weight of charcoal, which, upon being burned, affords an ash composed of silica, alumina, oxide of iron, with traces of lime and manganese.

The Tar Lake of Trinidad is about 3 miles in circumference, and of an unknown depth, and forms the largest bituminous deposit in the world. It is situated in the highest part of the island. The odour from it is perceptible for many miles. To a distant spectator it appears like a sheet of water undisturbed by the least ripple; on a nearer approach it looks as if it were glass. It has been found that this bitumen, which is quite solid at the surface, is soft when cut into, and is interspersed with cells, which contain petroleum. In hot weather the surface of the lake softens to the depth of an inch, and therefore cannot be walked upon at those seasons. Large fissures frequently occur, and from this circumstance the pitch is supposed to float upon a body of water. In the neighbourhood of the lake liquid bitumen is found in holes and fissures in the ground, to the depth of about 2 inches; the soil also presents indications of volcanic action. The bitumen from this lake does not easily burn, but a gentle heat renders it ductile; it is not much used for asphalting purposes. When mixed with grease it answers well for coating the bottoms of ships, to protect them from the small worms known as *teredines*.

Some years ago asphalt produced an industrial fever almost without a parallel in manufacturing annals; at that period the product was extolled beyond measure, and uses were assigned for it in every branch of the arts and manufactures, even in cases where common sense alone might have been sufficient to demonstrate its inefficiency. A reaction, unfortunately too complete, soon took place, and it fell into undue discredit; but now it is slowly recovering in public estimation, and it is certain that its valuable qualities of plasticity, fusibility, adhesiveness, impenetrability to water, &c., unchangeableness under ordinary conditions of the atmosphere, turned to account with discrimination and judgment, will render lasting services to many departments of industry.

The chief use of asphalt, at present, is in making floors and laying down pavements and roads.

A recent application consists in preparing conduits of large dimensions, by means of thin tubes of sheet iron, if covered externally with a coating of bituminous mastic, of from 1 to 1½ inch in thickness. These economical conduits were devised by M. Chameroi, and employed by him in Paris. Pipes of bituminized glass were proposed by M. Hutter, and made in the glass-works of Rive-de-Gier, but did not come much into use.

It appears, however, that bituminous mastic or asphalt may be applied to a variety of purposes, analogous to those which have just been indicated. The tar may serve directly, and without being transformed into asphalt, for several rather important uses. It has already been employed for impregnating paving-flags of sandstone, bricks, and other building materials; it communicates to these different objects the qualities which belong to itself. It is sufficient for this use of it to heat the tar to 302° Fahr. (150° C.), and to plunge in it the sandstone or other materials of loose texture for two or three hours. The muriatic acid towers of alkali works have been constructed of such materials, and answered exceedingly well.

Earl Dundonald first proposed to make pipes, pillars, pedestals, bases, &c., from Trinidad bitumen. Combined with cloth, he proposed to make it useful as a covering for ships' bottoms, between the vessel and the metallic sheathing, and as a lining for coffins. Another, and the most useful of his applications of this important substance, was the coating of electric telegraph wires.

Bricks of very bad quality become excellent for various purposes after being saturated with mineral tar (see page 363).

It is a very remarkable fact in the history of the useful arts that asphalt, which was so generally employed as a solid and durable cement in the earliest constructions upon record, as in the walls of Babylon, for example, should, for so many thousand years, have well nigh fallen into disuse among civilized nations.

France has lately been most diligent in rendering this article subservient to her comfort, so much so that her capital and large cities may be said to have become as museums of asphaltic appliances. The mines of asphalt in Alsace offer, on account of their quality, considerable advantages and inducements for her advancement in this department.

For asphalting roads, streets, &c., the two great requisites are, first, a concrete or bituminous stone, where the mineral constituents are so blended and enveloped in the bitumen as to be unaffected by contact with air or moisture for any length of time, and also to be able to resist sudden changes of temperature without being injured thereby; this forms the basis of the asphalting. Secondly, a mastic or bituminous cement, which may be occasionally used with the former to give it more fluidity, and which is in like manner proof against air, moisture, and sudden changes of temperature.

The best concrete is thought to be that from Neufchatel; it is massive, of irregular fracture, of a liver-brown colour, and is interspersed with a few minute spangles of calcareous spar; it is easily scratched by the nail, but is still very irrefrangible. When exposed to heat it evolves a fragrant ambrosial smell, a property which distinguishes it from factitious bitumen. Its density is 2·114, or nearly equal to that of bricks. When treated with oil of turpentine it affords 80 per cent. of a white pulverulent carbonate of lime and 20 per cent. of bitumen.

The qualification giving its superiority to native bituminous concrete and mastic over artificial asphalt, is the intimate combination of the mineral and organic constituents that enter into their composition. No artificial preparation of this kind, whatever may be the pains bestowed upon it, can be so homogeneously, or its constituents so closely combined, as the natural compounds, for no means are employed to produce these necessary qualifications further than a comparatively feeble heat, whereas the natural substance must have been formed under the influence of a high temperature and an enormous pressure; hence the intimate union of the two principal ingredients is exceedingly perfect.

The concrete from Neufchatel may be rendered suitable for asphalting by mixing with it a definite amount of the mineral tar of Seyssel or Bechelbronn, the mixture being rendered homogeneous by fusing it in a sheet-iron caldron. Common tar is sometimes used for the purpose, but petroleum is much to be preferred.

At Lobsann, the asphalt is purified, as before stated, by the action of boiling water, and is subsequently fused by itself, to disengage water and volatile impurities. After the process of purification, it is melted and incorporated with bituminous limestone, pulverized and dried. When the mixture is sufficiently consistent it is brought to a table on which sheets of paper are laid, and upon these a square frame, intended to receive the plates of mastic, is placed; the mastic is poured out and spread by means of a heated iron roller. There is a division in the frame, by which two plates are obtained, making together a little more than a square yard. The plates are sprinkled with bituminous sand, and may then be piled up in stock or packed in bales. They are used with the sheet of paper beneath them. When laying these plates they are united by a hot iron, and can be removed and soldered afresh in a similar manner, if required.

The beautiful mosaic asphalt of the Place de la Concorde in Paris was laid as follows:—The ground was made uniformly smooth, either in a horizontal plane or with a gentle slope to carry off the water; the curb stones were then laid round the margin by the mason, about 4 inches above the level. This hollow space was filled to the depth of 3 inches with concrete, containing about a sixth part of hydraulic lime, well pressed upon its bed. The surface was next smoothed with a thin coat of mortar. When the whole mass had become perfectly dry the mosaic pattern was set out upon the surface, the moulds being formed of flat iron bars, rings, &c., about half an inch thick, into which the fluid mastic was poured by ladles from a cauldron, and spread evenly over.

The mastic was made by roasting the asphalt in an oven about 10 feet long and 3 broad, to bring it to a friable state; the bottom of the oven was sheet lead, and was heated by a brisk fire beneath it. A volatile matter (petrolene), to the amount of the one-fortieth of the weight of the substance, was driven off, and the residue, after roasting, became so friable as to be easily reduced to powder and passed through a sieve, having meshes about one-fourth of a square inch. The bitumen destined to render the asphalt fusible and plastic, was melted in small quantities at a time in an iron caldron, and then the latter in powder was gradually stirred in, to the amount of twelve or thirteen times the weight of the former. When the mixture became fluid nearly 2 gallons of very small gravel, previously heated apart, was stirred into it; and as soon as the whole began to simmer and acquire a thick syrupy consistence, it was fit for use. It was then taken in buckets and poured into the moulds.

Asphalt has been laid down in a great number of the public places and streets of Paris. The pavements are said to give great satisfaction, from their continued cleanliness and resistance to the air and general traffic. In London, its application to paving purposes has not been so successful as anticipated, owing to its slipperiness in damp weather.

In making asphalt pavements it is essential to boil the bitumen thoroughly, in order to expel the water and volatile oils, with which it is always impregnated, or else it will not, when laid down, resist so effectively as it might the extremes of heat and cold, neither will it remain unaffected by wear and tear. In preparing the natural asphalt, it is better to pulverize the rock by means of heavy iron rollers, than to disintegrate it by heat, as described in the foregoing paragraph; in both processes for sifting the dust, however, a sieve is employed of ten meshes to the inch.

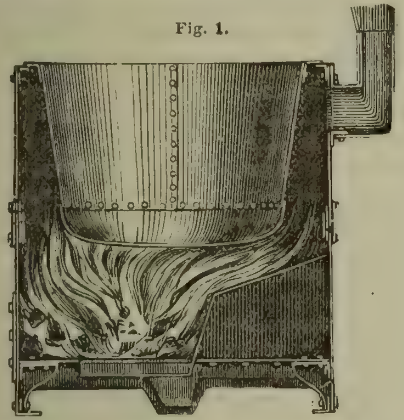
The object of the trituration is to convert the asphalt into mastic. For this purpose a certain quantity of vegetable bitumen is added, proportional to the quantity of asphaltic rock then transformed into asphalt powder. Thus, for those operations in which the cement requires to be endued with considerable elasticity, the proportion of bitumen ought to be greater; the contrary will be the case for firm and hard substances; and this proportion will still be different when the mastic is employed as a natural mortar.

In certain cases asphalt is used in the state of powder, and not in the form of mortar; but this mode of applying it presents disadvantages which it is necessary to avoid, in order to obtain the conditions required for its good applications.

The most advantageous use of natural or artificial mastic consists in applying it to the purpose of obviating the bad effects arising from moisture. It is excellent for protecting houses against damp; in this case it ought to be applied in thin layers to cover the whole surface of the ground. It may be used as a roofing; for cementing tanks, fountains, and cisterns, which it protects from any infiltration; as a substitute for pavement, macadam, and flags, in roads, courtyards, footwalks, &c. Terraces are rendered impermeable to moisture by means of a layer of asphalt, and in such cases it proves a highly economical substitute for sheet lead.

In CLARIDGE'S process of asphalting the blocks of mastic are fused in a portable boiler, similar to Fig. 1, and a quantity of mineral tar added, in the proportion of 1 lb. to every cwt. of the mastic. The tar is fused in the boiler, the mastic then introduced to the amount of 56 lbs., and the whole repeatedly stirred to prevent depositions. As soon as the contents of the boiler have been properly melted, the cauldron is covered over for a quarter of an hour, after which the remaining quantity of the mastic is added, and its fusion proceeded with as above, the process being repeated until the boiler is full, allowing an interval of from ten to fifteen minutes between each operation. When the mastic is sufficiently fluid it will drop freely from the stirrer, and jets of light smoke are observed to issue from it. If stiff mastic be required, the proportion of tar is lessened, and a quantity of coarse grit or river sand, to the amount of 20 or 30 lbs. to the cwt., added.

Fig. 1.



In laying the asphalt, the greatest attention and care must be devoted to the preparation of a solid and dry foundation. This is usually accomplished by removing or ramming the loose earth, and placing upon the bed a layer of coarse sand mixed with powdered limestone, in the proportion of seven parts of the former to one of the latter, and the whole pressed or beaten solid; upon this a second layer of finer materials is laid, compacted, and levelled; the bed thus prepared is allowed to dry before coating it with the mastic.

Fig. 2.

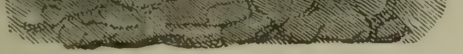


Fig. 2 shows the manner in which ordinary asphalting is laid down. In this figure, C is the bed of coarse concrete, B the second and finer layer of the same material, and A the superior layer of asphalt.

Unless the base, or concrete, be perfectly dry when the mastic is poured on, the work will not be successful, for the water will be converted into steam, which, issuing through the fluid mastic, will cause the formation of holes in the latter, or blister it, and ultimately the surface will crack. For this reason, winter is the worst season for laying down asphalt, except in places under cover. To counteract in some measure the evil arising from the formation of steam, it is found advantageous to sift fine cinder dust over the bed of concrete previous to the laying on of the liquid mastic. The depth of the layer of mastic is regulated by slips of wood, so arranged as to divide the surface into compartments of convenient size, and when laying the asphalt these compartments are filled up alternately; in this way there is no fear of one part being injured or defaced by the workman, as the alternate layers will be quite stiff when the intermediate spaces are being done. A curved wooden spatula, to which a straight rule of the breadth of the compartment of asphalt, and the ends of which move upon the slips of wood embedded in the concrete, is affixed, is rolled back and forth immediately after laying on the mastic, to bring it to the proper level.

When the surface is to be retained smooth, a mixture of equal parts of fine sand and slate dust, or 2 parts of sand and 1 of hydrated gypsum, or powdered chalk, is sifted over it before it is completely set, and rubbed in with a flat heavy wooden tool.

For roads and pavements, fine river gravel, or coarse grit, is scattered thinly over the surface of the mastic before it is hard, and beaten into it.

When asphalting suspension bridges, a sheet of canvas is generally spread over the concrete.

In asphalting damp places, such as cellars and foundations, a brick invert is always laid in asphalt beneath the concrete. The manner of doing this is by placing the bricks in rows at the proper depth and slope, and pouring a coating of asphalt about a quarter of an inch thick upon them. Before the mastic solidifies, the bricks are separated a little by passing a knife between them, thus affording the mastic an opening by which to seal up more thoroughly the connection. The concrete is afterwards laid upon this bed, and the layer of mastic upon this in the usual way. The thickness of the layer of mastic varies according to the attrition to which it is to be subjected; but the usual depth is from a quarter to one and a quarter inch.

In France, the following are the operations pursued in laying it. The general preliminary is to dress the ground, and beat it down well so as to render solid; it is then covered with a layer of pitch, 4 inches thick, and this is again covered with a thin layer of mortar mined with fine sand.

The pitch is left to harden for some days, to avoid the bubbles and swellings which would otherwise appear on its surface, after which the asphalt is spread upon it to the thickness of half an inch or more.

The ingredients are applied in the following proportion per square mètre—10¾ square feet:—

FOR HALF AN INCH.		
Mastic,......	44	pounds.
Gravel,......	26½	do.
FOR THREE-FIFTHS OF AN INCH.		
Mastic,......	53	pounds.
Gravel,......	30·8	do.

It has been acknowledged that the flooring of stables is of great importance to the health of the horses; this has caused a particular flagging to be sought after, which consists in spreading an asphaltic pitch of four-fifths of an inch in thickness on the ground, previously well dressed and beaten; then, by means of a grooved iron roller which is drawn along the band or belt of bitumen, a paving in relief is obtained, which drains off the water well, and resembles that laid in the ordinary manner.

It is in works connected with lines of railway that the use of bitumen is most fully appreciated. Thus, the copings of arches, of tunnels, and bridges, when covered with a coating of pure bituminous mastic, unmixed with gravel, completely prevent the infiltration of rain-water. As the earth-covering above might contain stones, which would penetrate into the bed of cement, a coating of clay is generally spread over the asphalt to the depth of 1 or 2 inches.

For constructing terraces, the following arrangements must be made:—

If the ground of the terrace is of masonry, the surface must be well put together, and the joinings carefully closed; it is then covered with a layer of asphalt half an inch thick, mixed with half its weight of fine gravel.

When the building on which the terrace is required is of timber, the flooring must be formed with planks at least four-fifths of an inch in thickness, arranged very close to one another, and firmly nailed to the supporting beams or joists.

This flooring is spread with a layer of pitch an inch or two in thickness, mixed with a little chopped hay or moss, to increase the elasticity of the ground.

The pitch having time to be well solidified, is then covered with the asphalt in the same manner, and under the same conditions, as in the case of terraces constructed on masonry.

The surface of the layer of asphalt ought to be grained over with fine sand, firmly compressed and beaten down, to intercept as much as possible the rays of the sun.

The application of two layers would afford still further security.

QUANTITY OF INGREDIENTS EMPLOYED PER 10¾ SQUARE FEET.

Asphalt,..............................	55	pounds.
Gravel,..............................	28·7	do.

By having the flooring of granaries asphalted, the different kinds of grain are secured for a long series of years from the damage to which they are liable when kept in the ordinary stores.

In the lining of cisterns and reservoirs, the danger to be chiefly apprehended is the infiltration and absorption of the waters which they contain. The mode of applying asphalt to obviate these disadvantages is exactly the same as when it is applied to the construction of store-pits.

Asphalt is also employed as *natural cement* in the construction of tunnels, to guard against the infiltration of water, and thereby avoid great inconveniences.

The principal points to be attended to in the construction of tunnels, are the same as when this kind of work is performed in the ordinary manner; only the stones must be perfectly dry, and brushed clean, if required, to facilitate the adherence of the asphalt, which ought to be from one-sixth to one-fourth of an inch in thickness between two consecutive stones.

Baboneau invented for the Val-de-Travers Asphalt Company a portable boiler, or melting vessel, provided with an agitator, by means of which the fusion and trituration of the asphalt with the bitumen, and then the mixture of the gravel with the mastic thus formed, can be performed at the place where the asphalting is to be done.

This improvement has done much to promote the application of asphalt for useful purposes; it is no longer necessary, in fact, to prepare in the manufactory the blocks of asphalt and bitumen, an operation which required a special apparatus. The substances, as they were found in nature, are now transported in sacks to the place where they are to be used; and the melting, trituration, and mixing, are performed on the spot at the moment when the substance is to be laid down. Moreover, the melting vessel is so ingeniously constructed, that it collects the gases, and absorbs the greater part of the disagreeable odour which melted asphalt evolves.

Artificial Asphalt.—This is prepared from the tar produced at gas-works. To prepare asphalt it is requisite to transform this liquid tar into a fatty pitch, and for this purpose the essential oils, which hold the solid matter of the tar in solution, must be completely distilled off; and the boiling must be continued till a sample, when cooled, becomes nearly solid.

The evaporation of the tar may be very well performed in the open air; but if it be desired to avoid the odour exhaled by the essential oils, and to collect the latter, which have a certain commercial value, it is necessary to conduct the operation in close vessels.

An apparatus, which gives very good results, consists of a still-retort of sheet iron, with a bottom made convex in the interior, placed immediately over a fire; the products of the combustion, after striking the bottom of the retort, circulate round it, then proceed under a second boiler to heat the tar contained in it, and from which the retort is replenished when requisite. This vessel, when three quarters full, contains nearly 24 cwts. of tar; it should be perfectly embedded in masonry; the capital itself, by which the volatile products escape, ought to be covered with materials that are bad conductors of heat, such as ashes, &c. Without these precautions the essential oils would condense and fall back indefinitely into the evaporating boiler. To collect the oils, they are made to pass into a tube cooled by a current of water proceeding in an opposite direction to that pursued by the vapours; they are then received in a close vessel. A tube, branching from the vessel, conducts the uncondensed products outside the building in which the distillation is performed. This precaution is necessary to avoid the risk of conflagration; for these condensable oils have always a certain tension, and consequently yield vapours tending to diffuse themselves in the atmosphere.

When the tar is brought to that state in which it assumes a sufficient consistence on cooling, it is withdrawn through a large pipe, and received into a third hemispherical boiler of cast iron.

To prepare the bituminous mastic directly from this fatty pitch, the latter is kept in a state of fusion by a supplementary fire placed under the cast-iron boiler, and chalk in sufficient quantity is then added. The chalk ought to be previously ground to a coarse powder, dried on plates of cast metal, and then passed through a sieve of iron wire. By adding heated chalk to the pitch, the mixture is accomplished better and more rapidly. The mastic is more solid in proportion as a greater quantity of chalk is added; but, on the other, it becomes less binding and more brittle. To mould the bituminous mastic, and thus impart to it a convenient form, a long table is spread over with cast-iron plates. A frame surrounds the table, which is subdivided into eight or ten compartments, by means of rules of about 6 inches in height, introduced vertically into grooves formed at equal intervals in the long sides of the frame. The eight or ten moulds obtained by this arrangement are coated internally with a paste, composed of sixty parts of water and forty of chalk, and which has the effect of preventing the adherence of the mastic to the sides of the mould.

Two barrels of tar, of 4½ cwts. each, or 9 cwts., lose by distillation one-fourth, which is composed of 1 cwt. 3 qrs. 15 lbs. of volatile essential oils, and 1 qr. 13 lbs. of water; there remain, therefore, about 6 cwts. 3 qrs. of fatty pitch. The essential oils procured by the distillation of gas tar have of late years received much attention from manufacturers, on account of their utility in the preparation of varnishes, and for lubricating machinery, as illuminating media; and for the preparation of a superior kind of lampblack. (See COAL-TAR DISTILLATION.) Again, by blending it with coal gas, it renders its illuminating power greater; for this purpose it is sufficient to pass the gas over the surface of a shallow vessel covered with these oils. Many patents have been taken out for apparatus to effect this mixture.

Asphalt, as generally used in this country, was formerly made from ordinary pitch, boiled down with a species of dark-brown bituminous limestone from the Jura mountains, previously ground and dried for the purpose. The limestone is, however, only employed in the manufacture of the better kinds, for chalk is often substituted, and some allege with results equally good. The proportions taken are regulated by the use to which the mastic is subsequently to be applied; and having mixed them they are boiled down to a thick liquid, after which the semifluid mastic is run into square or circular moulds to cool, when it forms blocks of about 140 lbs. each.

Sometimes ground or fine sand enters into the asphalt in equal proportion with the chalk or limestone; but, in some instances, only half as much sand as of chalk is used. It is necessary during the fusion to keep the contents of the caldron well stirred, as well to prevent the tar adhering to its bottom, by which it would get burned, as also to bring the ingredients into intimate combination and to give the mass a homogeneous composition. As soon as the whole is thoroughly mixed, the proper consistency acquired, and aqueous and oily vapours are found to be disengaged only in very minute quantities, the asphalt is run off into the moulds as before stated; and in this form it is conveyed to the place where it is being laid down.

Dr. G. HAND SMITH has recently patented a process for making artificial asphalt, waterproof concrete, &c., which promises to become of great value for sea walls, docks and harbour works, &c. His invention consists in filling up the interstices of any porous substance, such as brick, burned or unburned clay, soft stones, plaster of Paris, &c., with pitch or tar which has been boiled to such a consistence that the pores or cells of the material used are completely filled with solid matter when cold.

Other hydrocarbons, resins, or gums, may be used instead of pitch and tar, but it is essential that the saturating substances, though naturally fluid or semifluid, can be so changed by boiling that they lose their fluidity when cold; or they must be, though hard under all ordinary temperatures of the atmosphere, capable of reduction by heat or otherwise to a fluid condition, so that they will penetrate the porous materials.

If tar is used, it is first boiled long enough to give it, when cold, about the consistency of pitch, although its fluidity is retained while it is kept hot. In the heated tar the brick, sandstone, or other similar porous material, is immersed until the pores are completely filled with the liquid. When thoroughly saturated the material is removed from the tar and allowed to cool.

When pitch is used, it is simply melted, and then the saturation of porous material effected as with coal tar.

Or a mixture of pitch and coal tar may be used, provided it has been previously so long heated that it will harden on cooling. Merely soaking in hot coal tar will not answer the purpose.

By an adaptation of this process, Dr. G. HAND SMITH produces a waterproof concrete of great beauty and durability, which can be cut or turned in a lathe, and is susceptible of a brilliant polish.

Clay, plaster of Paris, or chalk, moulded or cast into any desired form, is saturated with gas tar, or pitch, or a mixture of the two, by immersion in a boiling bath, until on removal no adhering film is perceived. Great care must be taken not to touch or handle the articles on removal from the bath, or they will probably fall to pieces. It is not always necessary for the fluid to penetrate completely through the object treated. Sometimes saturation to a slight depth only is desirable.

Without being allowed to become perceptibly cool, the saturated material is then heated in an oven, to drive off the volatile portions of carbon or other volatile matter, so that only the solid and non-volatile portions of the carbon shall be retained in the pores.

The degree of heat to which the articles are subjected of course varies somewhat with the material used and the precise result sought to be obtained. The heating and cooling should be gradual. The proper heat is usually indicated by the loss of odour and the toughening of the material treated.

If the bath consists entirely or nearly so of pitch, it may be heated to a very high temperature, and in some instances no after-heating of the porous material in the oven will be necessary, as the heat imparted in the bath is so great that in cooling in the air after immersion sufficient volatile matter will be driven off. If the objects are to be heated to redness, they must be inclosed in retorts to prevent the combustion of the carbon.

Pulverized clay, plaster of Paris, chalk, and the like, may be first mixed with coal tar, pitch, &c., moulded or pressed into form, and then subjected to heat, as above described.

The following is the mode of making artificial asphalt or "carbonite" (as its inventors term it), for building sea walls, which has been devised and patented by G. Hand Smith and H. C. Paterson. The new transfer docks in Glasgow are to be built of this material. The outer walls are of moulded blocks laid in courses, the space between being filled in with the carbonite while hot.

Two mixtures are made. The first mixture or compound is thus composed:—

Ordinary green or boiled coal tar, about........	15 to	25 parts by weight.
Small broken stones, sand, or shingle, about......	985 to	975 parts by weight.
	1000	1000

It will be seen that the quantity of coal tar is very small. It should be heated before it is used, so that it may flow readily. If instead of green or boiled coal tar, the ordinary tar from which the heavy oils have been distilled should be used, a larger proportion will be required

The above ingredients are mixed in a strong pug mill, at a heat which is gradually increased until the pebbles become adhesive to the touch. When the ingredients have been brought into this condition, a second mixture is introduced into the mixing apparatus This mixture is thus prepared:—Clay and pitch are taken separately, in about the following proportions:—

Pitch about............	250 to	335 parts by weight.
Clay, dried or anhydrous, about...............	750 to	665 parts by weight.
	1000	1000

The solid pitch is ground with the dry clay, and the powder thus produced is thrown into the pug mill, while its contents are adhesive to the touch. The proportion of the pitch mixture should be about 12 per cent., viz.:—

Of the first compound, about	880 parts by weight.
Of the second compound, about	120 parts by weight.
	1000

The whole mixture is then shut in by a close fitting lid (the vessel must be provided with a safety valve, and may be heated by a steam jacket or otherwise), and the heat raised to about 250° Fahr., or to a higher temperature in proportion to the hardness which it is desired to impart to the manufactured material; it should not in any case be carried higher than about 350° Fahr., as at higher temperatures the plasticity of the mixture is destroyed. The mixed ingredients must be well agitated, so that the vapours generated may diffuse themselves uniformly throughout the mass. So soon as a sample is found on moderate compression to become hard and to be tough when cool, the "carbonite" is removed while hot to moulds, where it is pressed and shaped into blocks of the required size, by machinery if requisite, though for ordinary purposes a hand rammer suffices.

A prominent feature of these carbonite blocks is that for sea walls or piers they can be cemented together with a suitable asphaltic cement beneath the surface of the water, and whilst exposed to the action of moderate waves.

Concrete thus produced is of very great toughness, and when fractured, breaks through the pebbles and stones composing its mass.

BLEACHING.—*Blanchiment*, French; *Bleichen*, German.—Under this designation is understood in general the elimination of colour from various substances by means of some chemical agent. In a special sense bleaching means the purification of certain organic fibres, and of textile fabrics made of them, from coloured and other impurities, which are either naturally associated with them, or are added for some purpose or other in the course of the manufacture of such fabrics. It is in this sense alone that bleaching is understood in this article.

Bleaching is, as already stated, the result of a chemical action of certain substances upon the colour of the fibre. The agent now almost universally employed is chlorine, which is used in the shape of bleaching powder—a compound consisting of chlorine, lime, and oxygen. For the preparation of this substance, its nature, &c., the reader is referred to the article Chlorine.

Bleaching is of very great antiquity, but where it originated is unknown. It may be reasonably supposed that, as soon as human knowledge extended to the manufacturing of clothing, the observation was made that the natural shade of colour in such fabric was destroyed by exposure to the atmosphere and rain, and also by occasional washing; hence the idea of bleaching, by constant exposure to light and moisture for a certain period, may have occurred. But though this proved very efficient, the necessity of having large fields at command, and the great amount of labour and the long period of time which the process required, made it an expensive one. Subsequently sulphurous acid was used and still continues to be employed in many cases.

A cursory notice of the older manner of bleaching, as well as a brief historical sketch of the improvements introduced from time to time, may prove interesting in this place.

The first operation was the steeping, which consisted in immersing the yarn and cloth in a cold alkaline lye, or in hot water; when the latter was used, the steeping lasted for three or four days, but if the bath was alkaline, forty-eight hours sufficed.

The goods after this steeping were washed and boiled for four or five hours, again washed, and exposed on the grass to sun and air for two or three weeks. After this period they were again boiled, or, as it was termed, "bucked," washed, and again exposed on the grass, or "crofted," as before. The alternate operations of bucking, washing, and crofting, were repeated five times, the strength of the alkaline lye being reduced at each successive washing.

Having performed these, the next course was the souring, which, till about the middle of the last century, consisted in keeping the goods steeped during several weeks in sour milk. A writer at this period, Dr. HOPE, suggested the use of dilute sulphuric acid instead of the milk, and by this improvement the time of souring was shortened to about ten or twelve hours. The bleaching was not, however, finished with this operation; the boiling, washing, souring, and crofting, had to be renewed and continued till the cloth appeared perfectly clear, and quite colourless. The period of boiling, &c., varied according to the quality of the goods; linens were seldom finished in less than six months, and cottons required from six weeks to three months.

It is unnecessary to enter into the explanations which older chemists offered concerning the changes effected during the above described course of operation; they have proved more or less inaccurate. Modern writers seem to agree that the principal action which takes place during croft-bleaching is the combination of the oxygen of the air with the colouring matter, resulting in a compound which can be dissolved out by water or alkaline liquors on boiling.

Before proceeding to describe the course of operations as now executed, a little attention must be given to the nature of the materials, and also of the impurities with which they are impregnated. Upon examination it will be found that considerable difference exists between a sample of cotton, hemp, or flax fibre, and one of wool or silk; hence the necessity of applying different methods for their purification becomes apparent.

The materials which enter into the formation of cloths and other fabrics are either of vegetable or animal origin; the first class includes cotton, flax, hemp, and some others; the second, wools and silks.

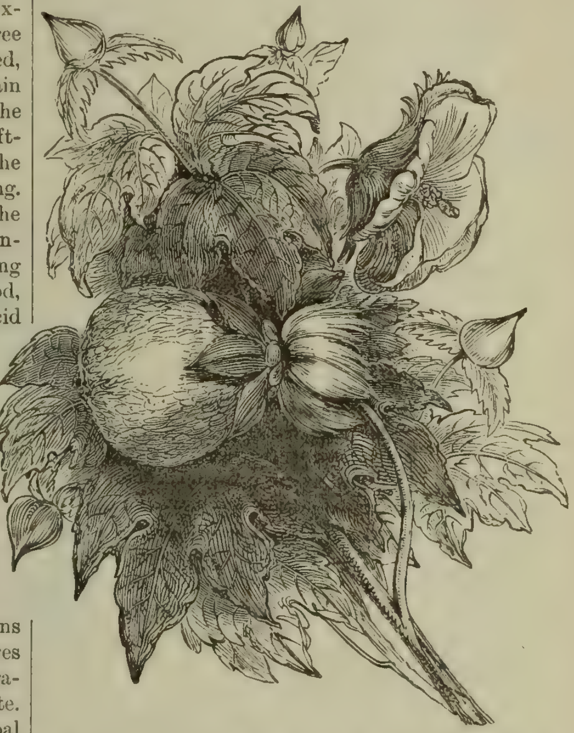
COTTON (*Coton*, French; *Baumwolle*, German) is the filamentous down enveloping the seeds of several species of *Gossypium*, a plant belonging to the natural order of *Malvaceæ*. The most important species are:—

1. *Goss. herbaceum*, Linn., an annual shrubby plant of about 3 feet high, indigenous in Asia and Egypt, whence it was transplanted to Asia Minor, South Italy, Sicily, Malta, and Spain. Fig. 1 is a drawing of the cotton pod and flower of this plant.

2. *Goss. barbadense* reaches a height of 15 feet, indigenous in the West Indies, but occurring also in Africa and America.

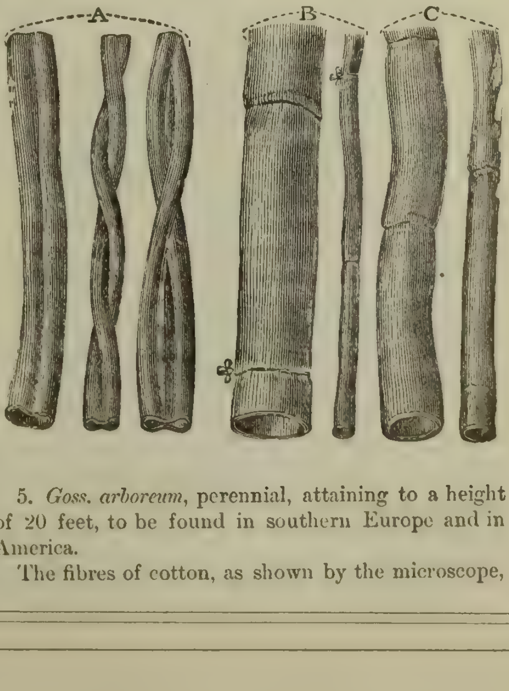
3. *Goss. religiosum*, with a brownish-yellow fibre, at home in China and India.

Fig. 1.



4. *Goss. hirsutum*, the hairy American cotton, of about 6 feet height, largely cultivated in North and South America and the West Indies.

Fig. 2.



5. *Goss. arboreum*, perennial, attaining to a height of 20 feet, to be found in southern Europe and in America.

The fibres of cotton, as shown by the microscope, are represented by the preceding sketch—Fig. 2—in which the fibres of cotton and flax are contrasted. The fibres, A, are from raw cotton prepared for manufacture; the fibres, B, are those of raw flax before spinning; and the fibres denoted by C, are those of unravelled threads of manufactured flax. All the fibres figured represent each $\frac{1}{200}$ of an inch in length, and are magnified 400 times in diameter. They vary in thickness from $\frac{1}{800}$ to $\frac{1}{3800}$ part of an inch. It will be observed that the cotton fibres, as thus revealed by the microscope, are somewhat flat, two-edged, or triangular, never or extremely seldom cylindrical, but contorted, especially when moistened, and occasionally widened out, in which case they are frequently marked with lines running in a direction oblique to the axis of the fibre. This construction causes the fibres to adhere to each other and causes cotton clothing to give warmth. The fibres of flax, on the other hand, are straight notched tubes with a smooth surface.

The principal constituent of the cotton fibre is cellulose, which forms the substance of the cell; over this lies a delicate skin, the cuticula, which is not composed of cellulose. We learn this from the different behaviour of the two towards certain reagents. A solution of cupric oxide in ammonia attacks the cellulose portion of the fibre, causing it to swell up into a gelatinous mass, but leaves the cuticula, which is broken into pieces, unchanged; on adding some hydric sulphate, and subsequently a drop of tincture of iodine, the cellulose becomes blue, the torn cuticula yellow.

Cellulose is insoluble in cold and hot water, in dilute acids and lyes, in alcohol, ether, fats, and volatile oils, but dissolves easily in concentrated sulphuric acid, and is likewise destroyed by strong solutions of caustic alkalies. Cream of lime, even hot, does not affect it; but if the lime is allowed to become dry upon the fabric, it soon reduces the fibre to powder—probably in consequence of the formation of carbonic acid and water at the expense of the carbon and the hydrogen of the cellulose.

Cellulose possesses the same empirical composition as starch, gum, and sugar, which is usually expressed by the formula $C_6H_{10}O_5$.

The other not mineral constituents of the cotton fibre are very little known; all that seems to have been ascertained about them is that they are gums, resins, and fatty matters. It is these substances which necessitate the purifying processes to which the fabrics have to be submitted, preliminary to the bleaching action proper.

Besides those natural impurities, there are those which the fabrics take up in the course of their preparation. Such are the weaver's dressing, which is usually starch or size, and the perspiration and filth from the hands of the workmen.

The task of the bleacher would be easy if he had only to deal with the vegetable fibres of the textile fabric, and the colouring matters naturally occurring in it; but the presence of fatty, and still more of the resinous bodies, renders the bleaching operation very complicated. These bodies are not readily attacked by chlorine, and if the operator were to persevere in the application of this agent until fats, resins, &c., had been eliminated, he would by that time also have destroyed the fibres of the fabric. Other means have therefore to be used before the treatment with chlorine can be resorted to.

The bleaching process, as now practised, dates from about the year 1828, when machinery was made to supersede manual labour. D. BENTLEY (of Pendleton) made the first efforts in this direction; and although his early proceedings were not adapted to successfully compete with the rapidly developing improvements of the succeeding years, yet they possess the merit of having given the first impulse to the movement. Among the foremost of those whose labours greatly contributed to the mechanical improvement of the bleaching operation is JOHN GRAHAM of Staleybridge. His arrangements, which greatly assisted to bring the bleaching process to its present simple and almost entirely mechanical form, have been adopted by nearly every bleacher in Great Britain. They are, besides having the advantage of speed in the manipulation, valuable on account of considerably lessening the quantities of the chemical agents required.

The whole operation of bleaching may be divided into the following stages, of which, however, one or the other can, according to circumstances, be omitted:—Stamping and ending; singeing; scouring with water; bucking with lime water and washing; scouring; scouring with caustic alkali and washing; treating with bleaching liquor; scouring; steeping; bucking with caustic soda or its carbonate; souring; washing and squeezing; mangling; starching and dyeing; calendering, folding, and stamping.

Stamping and Ending.—This affords little interest to the chemist; but to make the subject as complete as possible, it will be briefly noticed. As soon as the goods enter the bleacher's establishment it is necessary, to prevent confusion afterwards, that each lot should be marked with the owner's name, so that at the termination of the work little difficulty may present itself in delivering the goods. With this view a person takes each piece, and stamps on one end the name of the owner with a brand of wooden letters dipped in coal tar, a body that remains unacted upon during the usual operations. By washing well with soap and rubbing between the hands, however, it will ultimately be obliterated. Some finer qualities of goods, instead of being marked with this material, have the initials or full name inserted in some indelible coloured thread, or with nitrate of silver, as the case may be.

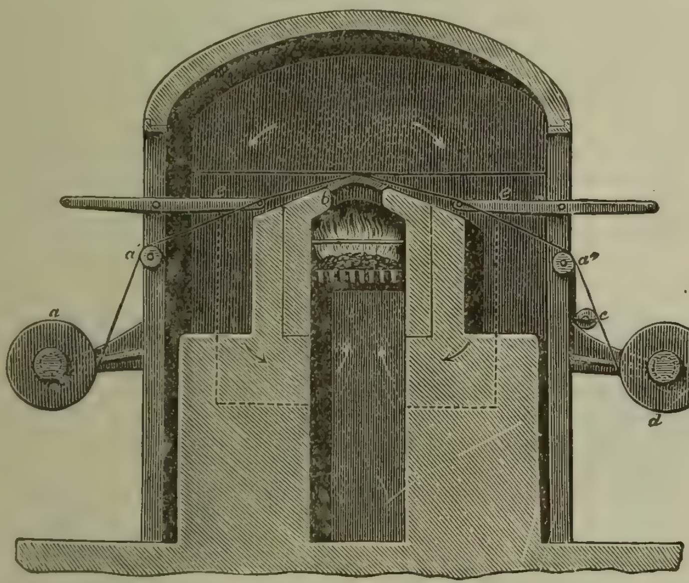
The several pieces are then stitched end to end, in order to facilitate the subsequent bleaching.

Singeing.—This operation is, like the above, a preparatory one, and consists in singeing or burning off the loose fibres or flocks on the surface of the cloth; were these permitted to remain they would very much injure the appearance of the bleached goods. The usual method of performing this part of the work is to pass the work over red-hot rollers at such a velocity that the body of the threads is uninjured, although the loose fibres are consumed.

A few years ago J. Hall, of Nottingham, proposed to effect the singeing by drawing the cloth over the open flame of gas, and the process is said to have worked well; but of late it has almost entirely gone out of use.

The apparatus employed for singeing is represented in Fig. 3. The cloth, which is wound upon the revolving drum, a, passes over the guide-roller, a', and is thence drawn across the red-hot plate, b. A second guide-roller, a'', brings it next in contact with a cylinder, c, which partially dips into water, and thereby extinguishes all sparks before the cloth is drawn upon the cylinder, d. Two frames, e, are so arranged that by their means the cloth can be brought into greater or lesser proximity to the plate. The plate is heated from below by an open fire, and the vapours produced are drawn off from the covered singeing space by two flues.

Fig. 3.



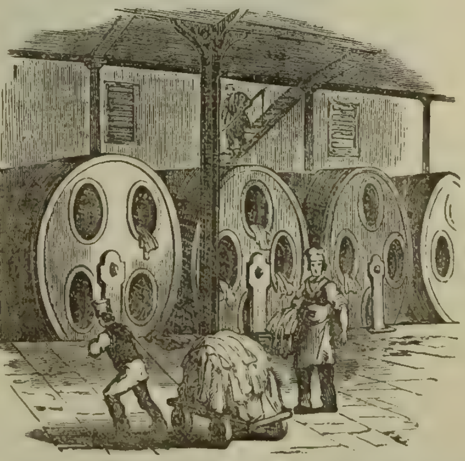
Goods which are to be printed with superior patterns and colours must be singed on both sides; ordinary goods, which come undyed into the market, are often not singed at all.

In some factories the singeing takes place after the bleaching; but the general experience seems to point to the advisability of giving precedence to the former operation.

Scouring.—The goods are next submitted to soaking and scouring. This operation requires some art as well as knowledge to perform it satisfactorily. Everything depends here upon an uniform soaking of all the parts, and this could only slowly be obtained if the cloth were thrown into the water in regular folds. To avoid such an expenditure of time the pieces are drawn through a tubular ring, the diameter of which is one-fourth or one-third of the width of the cloth, whereby they take the form of a rope; they are then coiled up, tied by a string to prevent their becoming loose, and thrown into a cistern. They remain here until they get thoroughly penetrated, after which the water is drawn off and replaced by some of 120° to 140° Fahr. (48°·8 to 60° C.), wherein the goods are left for thirty-six hours, during which time the glutinous matter of the size enters into fermentation; this process must, however, be checked as soon as it has reached the proper limit, for, if allowed to go on without restraint, putrefaction would ensue, which would finally attack and destroy the fibres of the cloth. Many bleachers dispense with the fermentation altogether, and prefer boiling the goods repeatedly in weak milk of lime or alkaline lyes. In the case of muslin goods, however, preference is generally given to the fermentation method, on account of the perfect manner in which it eliminates the gluten. After the decomposition the pieces are washed or scoured in a vat, either by the dash-wheel or some other convenient apparatus.

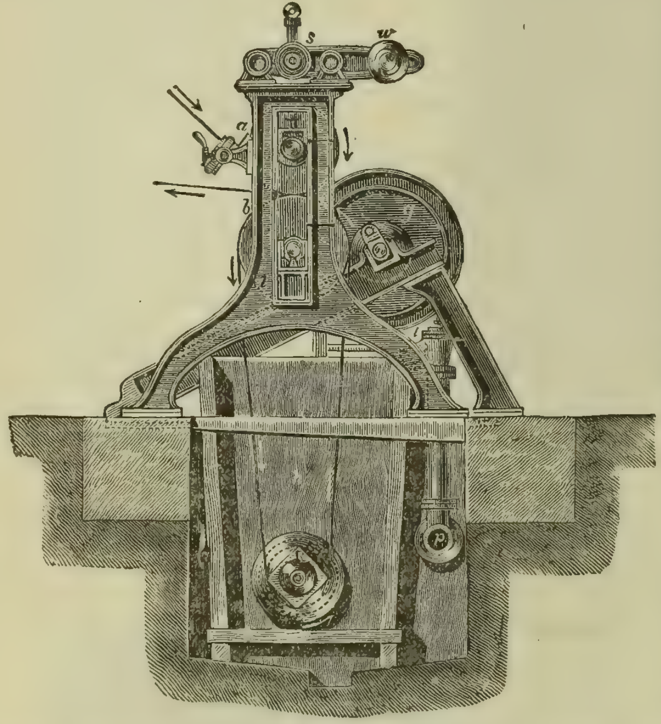
Fig. 4 is a drawing of the dash-wheels. A cylindrical box, of about 6 feet diameter and 2½ feet depth, revolving upon its own axis, is divided by two vertically intersecting perforated plates into four divisions. Each of the divisions is provided at the front with an opening, through which the pieces of cloth are introduced, whilst the water enters on the opposite side. The wheel is set into slow motion, causing the cloth to toss from side to side, and thus washing it thoroughly in eight to ten minutes.

Fig. 4.



A scouring machine of still greater effect is that constructed by C. Mather. Fig. 5 represents a lateral. Fig. 6 a front view of it. By this machine the cloth, the ends of which had been joined to one another, is taken several times through water, and after each passage squeezed between cylinders in order to separate by friction the particles of impurity. The cylinders *a* and *b* are of wood (usually pine); *a* is about 8 feet long and 1½ foot in diameter, *b* of the same length, but 2 feet in diameter; the middle portion of the upper cylinder is thickened by a strong piece of cloth, *a'*, the purpose of which is to increase at that spot the pressure of the cylinders upon the goods; *c d* is a wooden beam provided with plugs, which conduct the piece in spiral lines from the upper cylinders to the cylinder *r*, and from this back again to the upper two; *h h* is the water trough in which *r* is fixed; *p* is a water pipe, provided with a valve, *t*; *m m* are two rings of glass or hard wood, fixed upon movable holders on both sides of the machine, which serve to regulate the tension of the cloth. The levers, *w*, press the upper cylinder, *a*, against the lower, *b*, and they govern thus the amount of pressure exerted upon the cloth passing through the cylinders; the screw, *s*, is capable of increasing the effect of the levers. In the operation the piece passes through the eye, *m*, over the cylinder, *a*, round this between *a* and *b*, over the beam, *c d*, through the water in *h h* round *r*, from whence it ascends across the back of *c d* to the upper cylinders, and repeats this way in the direction of the arrows, until it finally leaves the machine at *a'*. It is obvious from the accompanying diagrams that two lots of goods are simultaneously washed in the apparatus, which enter on left and right sides, and leave it together at *a'*.

Fig. 5.

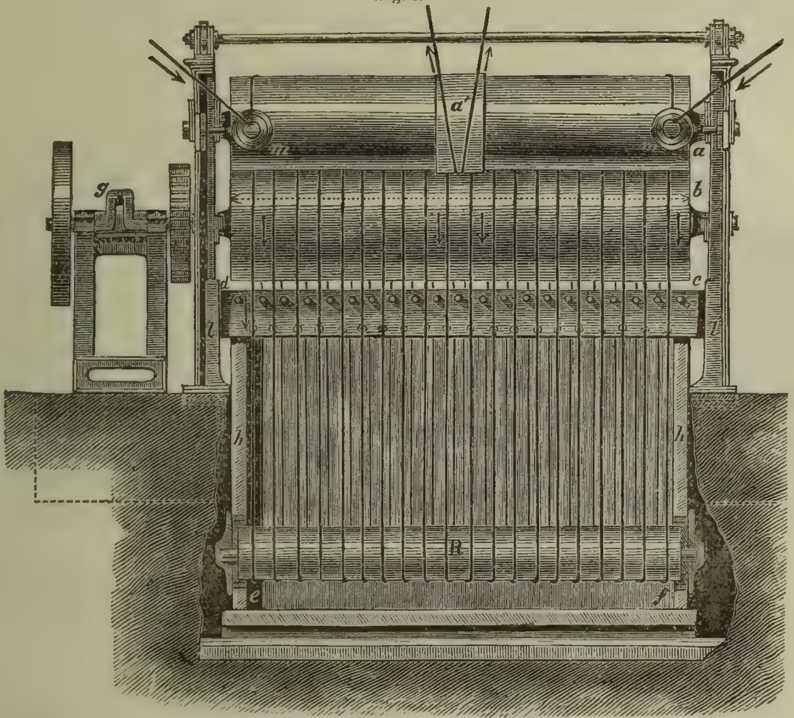


This machine is capable of scouring 800 pieces (of 35 yards each) in an hour, and requires only about 200 lbs. of water for every piece.

Bucking.—The boiling or bucking with alkaline liquids has for its object the abstraction of the small portion of the fat naturally present in the fibre, and also that casually added; likewise, the removal of the residual portions of the gluten. For a long time potash and soda lyes were used for bucking the goods, but at present lime is used, and is found to answer admirably, in consequence of its energetic action upon fatty matters, forming with them an insoluble calcareous soap. It is not known who first employed it, but it encountered a great deal of opposition. It was contended that it destroyed the fabric, that it formed with the fatty bodies insoluble soaps, which could not be washed away, and, worst of all, that the lime soap united with the colouring matters, and thus gave the goods a dark appearance. But none of these objections are valid; the first can only happen through an immoderate use of lime; the second difficulty is got over by decomposing the lime soap with an acid; the last grievance is true enough, but is still no grave impediment to the use of lime, since the dark colour is easily destroyed during subsequent operations. The treatment with lime has the advantage that the resinous coating is removed from the fibre, and that consequently the chlorine has ready access to the latter. Experiments have shown that the strength of the cloth is not injured by being boiled with lime water for two hours; it is necessary, however, that it should be of a certain strength, and likewise that the pieces of cloth should be covered over with the lye, stirred repeatedly during the boiling, and washed immediately after being taken out, in order to prevent the absorption of carbonic acid, which would form carbonate of lime on the cloth, and thereby destroy it in a great measure. It has been also observed, that ebullition in water, or in a soda lye, marking 3° Twaddle, or 1·015, at a pressure of ten atmospheres, notwithstanding that the alkaline liquor may, during the boiling, acquire double the density which it originally possessed, does not affect the goods; neither are they injured by boiling under atmospheric pressure in a lye of 1·070 specific gravity, or 14° T.; or by being immersed in a solution of bleaching powder, capable of decoloring three times its volume of a test solution of sulphindigotic acid for eight hours, and by being afterwards dipped in sulphuric acid of specific gravity 1·067 or nearly 14°; or by being steeped for eighteen hours in hydrochloric or sulphuric acid of 7° T. As a rule, however, the bleachers seldom employ solutions of the strengths specified, since the weaker liquors yield equally good results.

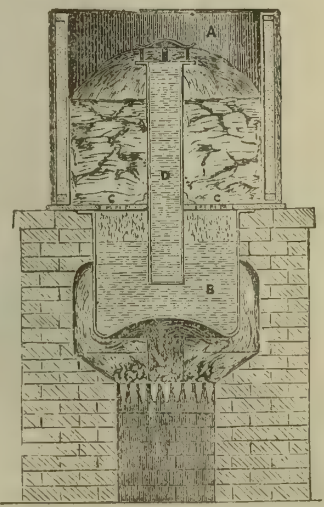
The boiler, or "kier," in which the bucking is executed, is either one in which the lye is in contact with the goods, or one which receives its lye from a separate vessel. Formerly the kiers were heated directly by the fire, and such is still the case in smaller bleaching establishments; but in all large works steam is employed for the heating of the lye. The simplest kind of boiler is represented in Fig. 7. This kier consists of two principal parts, one, A, is the large receptacle for the cloth, and the lower part, B, is the boiler where the lye is submitted to the action of the fire. There is a communication between these two parts at C C, which consists of a strong iron or copper grating. In the middle of this grating a pipe, D, is firmly screwed; through this the lye in the lower pot ascends during the boiling. It is surmounted by a cap, by which the ascending liquid is made to spread over the goods, and return to the pot to be again heated. The upper part of this kier may be constructed of wood or sheet iron, well riveted and joined to the lye-pot; the latter may be of copper. As the object is to have an elevated temperature, the top vessel is shaded with a casing of wood, between which and the boiler is packed sawdust, charcoal, or some non-conducting material, so that no reduction or loss of heat may be experienced by conduction or radiation. F is the grate whereon the fire which heats the whole rests.

Fig. 6.



On applying the heat, the liquor in the lower vessels does not boil till the temperature exceeds 212° Fahr., but as the pressure is less in the pipe, D, in the course of a short time the liquor contained in it reaches ebullition, and steam is generated, which rushes out at the top, whilst the expansion of the body of liquid causes a column, more heated and denser, to rise, which throws that already in the pipe out upon the cloth. In this way the operation is conducted, a continuous stream falling upon the cloth, and percolating through the grating into the boiler, where it takes up a fresh portion of heat, and reascends as before.

Fig. 7.



Sometimes the end of the pipe, D, reaches midway between the grating and real bottom of the lye-pot, and the boiling is continued as in the preceding case. Eight hours' boiling is the usual period for the completion of the first bucking, but this is sometimes prolonged to ten and even fifteen hours. At the conclusion the spent lye is drawn off by a pipe and stopcock at the bottom of B, and the goods are removed to the souring machine.

Laurie, of Glasgow, modified the foregoing apparatus in the manner represented in Fig. 8. A B C D is a large wooden tub, or "kier," into which the cloth is put, and which is firmly fixed at C and D to a copper or cast-iron boiler, C E F D, as seen in the drawing, wherein the lye is contained: it is covered lightly by a plate of the same material, a communication being made by means of a pipe, K, between it and the top vessel. A pump, G, is in connection with it, by which the liquid is raised and discharged upon the goods in the kier through the pipe, P. M O is a metallic plate upon which the pumped lye falls, and is dispersed all over the cloth. The whole is heated by a furnace as in the preceding.

Fig. 8.

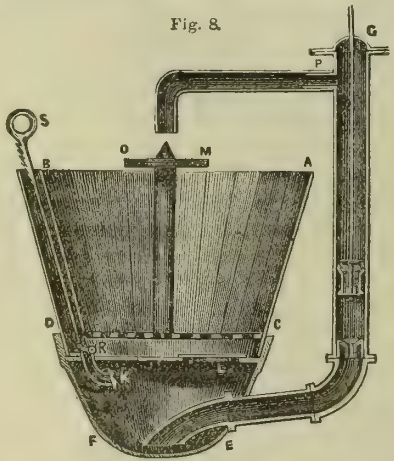
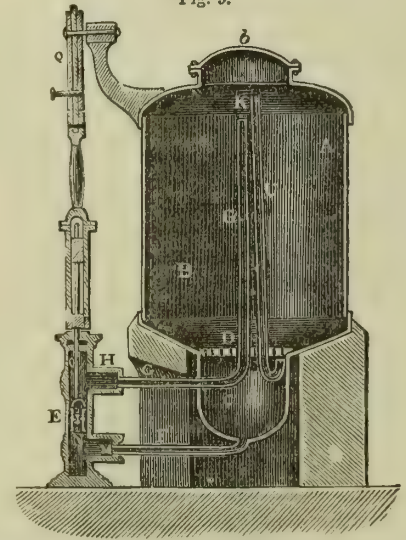


Fig. 9.



The cloth is placed upon a movable frame or rack, and introduced into the upper vessel; the fire is then lighted, and while the contents of the lower vessel are reaching ebullition, the pump is kept in action; but after the lye begins to boil, the elasticity of the vapour keeps up the current, and the pump is no longer worked. As the liquor falls through the cloth, it returns to the boiler by the pipe, K, the valve, R, attached to this pipe, being opened by means of the handle, S.

Similar in principle is the apparatus of A. Robeson, of Newport, U.S., represented in Fig. 9. A is a copper vessel, divided by a perforated plate, D, into two compartments; E is a pressure pump connected by the tube, F, with the lower division, C; the tube, G, passes from the valve chamber, H, of the pump through compartment C, very nearly to the top of the upper division, B, where its mouth is covered with a concave disc, K. L and M are the valves of the pump, N the piston, O the piston-rod, which is set into up and down motion by the excentric disc, Q. The tube, R, which is provided with a safety valve, S, conducts steam from a boiler into the upper part of A. A tube, U, runs parallel with G, into compartment C, ending a little below the perforated disc, and is provided at this end with a small safety valve.

The goods to be bucked are laid around the tubes G and U, in the chamber, B, to the height of the latter tube. The lye is placed into chamber C, which can, if required, be heated. By working the pump the lye is pressed against the deflector, K, whence it is spread over the fabric. On allowing steam to enter through R, the lye will be driven right across the goods down into C. If the pressure of the steam becomes too great, the valve at the lower end of the tube, U, opens, and then the steam enters the lye in C, where it condenses.

The spent lye is removed from C by a tap (not shown in the drawings); the goods and the lye are introduced into the cylinder by the circular opening *a*, which afterwards is closed with the cover *b*.

The kier represented in Figs. 10 and 11 has been devised by Graham. It is about 8 feet in diameter by 6½ in depth, and is heated by steam injected through a pipe from a high-pressure boiler. The central pipe is about 8 inches in diameter; it is surmounted by a cap, against which the liquor is forced by the pressure of steam from beneath, and distributed over the goods. The kier, when in use, is secured by a well-fitting cover and screws, and any excess of elastic vapour which may have accumulated during the period of bucking, which generally lasts fifteen hours, is carried off by a pipe inserted into the shoulder of the kier.

An improved form, devised by R. Kay of Busby, Renfrewshire, of the preceding apparatus, is shown in Fig. 12. The bucking cylinder, A, is the same as in Graham's arrangement; its top opening is closed during the scouring with the cover B. The vertical steam tube is connected with the cylinder at the bottom through the tube C, from which a pipe, E, provided with a tap, branches off in a lateral direction, by which arrangement the tube C serves a twofold purpose: it conducts steam into the cylinder, and takes away from it the spent lye. The circular false bottom, G, is perforated by rectangular holes, and has in its centre a large opening, to which the tube H is fixed; this tube becomes, a little above its joining, narrower, and rises to near the top of the cylinder, where its opening is surmounted by a screw, I, to which a valve, K, is fixed. The valves can be adjusted higher or lower.

The goods are packed round the tube, H, up to near the upper end of it; the valve, K, is screwed down upon the mouth of the tube, H, and the cover, B, is put on. On tap D being opened, steam enters, and ascending through G, moistens the fabric. When the goods have become thoroughly saturated, the steam is turned off, cover B is removed, the valve K screwed higher in order to leave the mouth of H open, and the cylinder again closed with B. The goods are now ready for treatment with the lye, which is supplied to A from a kind of cistern, M, through pipe P; the lye is heated by steam brought into M through pipe O. Whilst allowing the lye to enter, the tap R is kept open for the escape of the air from A. When the liquid covers the goods, tap Q is turned off, and tap D again opened; the boiling lye is driven through H against the screw I, thrown from here down upon the goods, comes across these into the partition below the perforated bottom, and is now projected again through H to the screw, and so on.

Fig. 10.

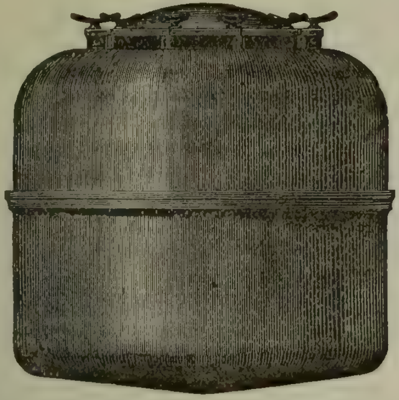
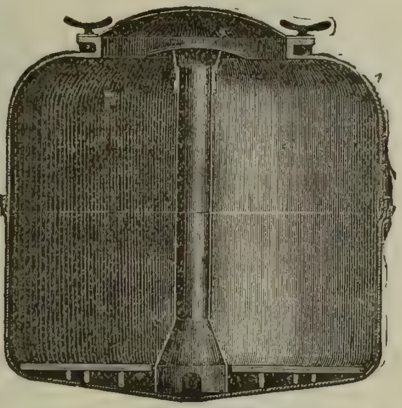


Fig. 11.



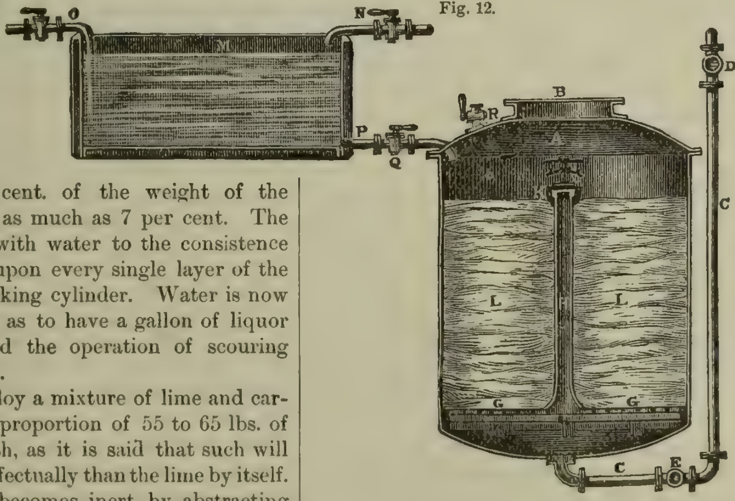
When the operation is finished, the supply of steam is stopped, the lye drawn off, and the goods are removed through the opening at B.

The quantity of lime employed varies; the ordinary proportion is about 3 per cent. of the weight of the goods, but some take as much as 7 per cent. The lime is slaked, mixed with water to the consistence of cream, and poured upon every single layer of the goods put into the bucking cylinder. Water is now added in such quantity as to have a gallon of liquor to 4 lbs. of cloth, and the operation of scouring carried on as described.

Some bleachers employ a mixture of lime and carbonate of soda, in the proportion of 55 to 65 lbs. of each to the ton of cloth, as it is said that such will scour the goods more effectually than the lime by itself. In this case the lime becomes inert, by abstracting the carbonic acid from the soda salt, and hence the caustic soda executes the work. Claussen uses caustic soda and lime.

It has been proposed to use, in the place of the caustic lime, a solution of lime in sugar. The advantages are said to be considerable: the fatty bodies are more easily saponified, the goods are certainly less affected, and the result of the scouring is such, as to do away, in some cases, with the necessity of treating with bleaching liquor. The goods are laid into a large vat, poured over with cream of lime, to which afterwards so much water is added that the liquor stands about a foot high over the goods; upon every 70 lbs. of fabric 1 lb. of lime is taken. The sugar-lime is next introduced, the vessel is closed, and heated for eight to ten hours under a pressure of 1½ atmospheres. After boiling, the goods are washed, and again subjected to the above treatment. A second washing follows, and rinsing in hydrochloric acid bath, of 1½° B., makes the finish.

Fig. 12.



The sugar-lime is prepared by thoroughly mixing a milk of 50 lbs. of slaked lime in 108 lbs. of hot water, with 15 lbs. of molasses in 36 lbs. of hot water. One lb. of this mixture is used for about every 13 lbs. of fabric.

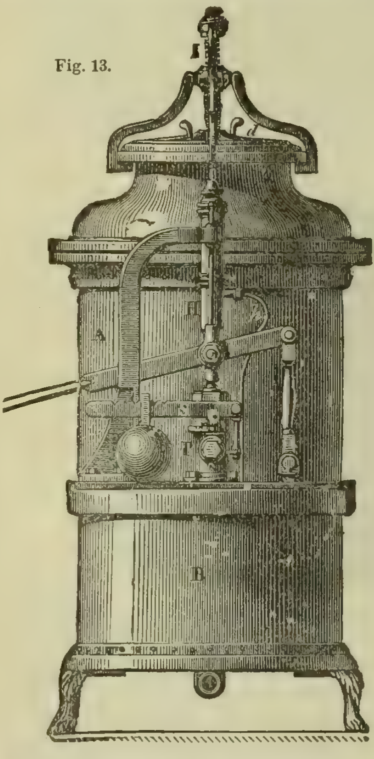


Fig. 13.

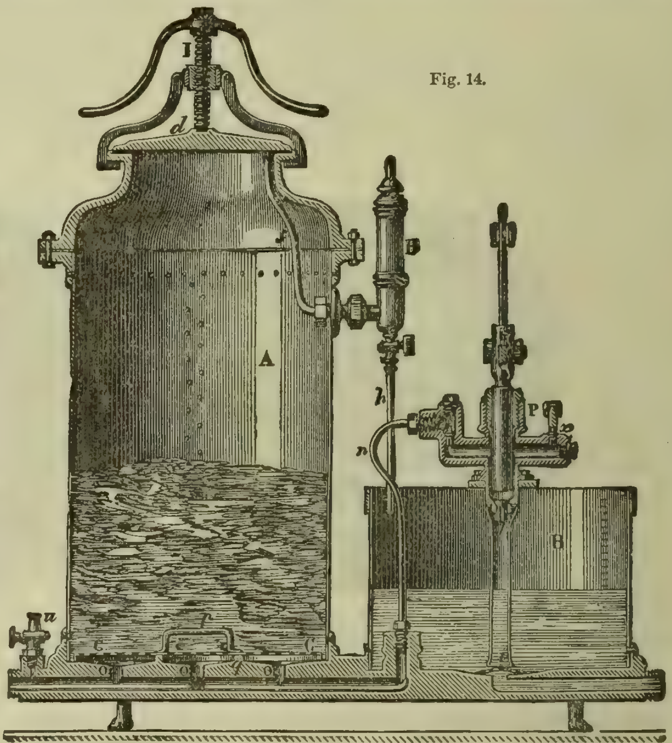


Fig. 14.

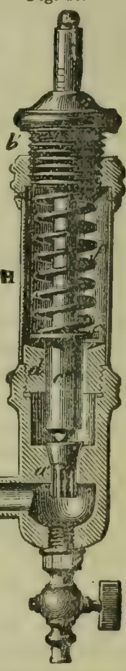
Metz, of Heidelberg, treats the goods with cold lye, as he believes the boiling to be injurious to the fibre; in his opinion, the only good of the boiling is the expulsion of the air from the interstices of the fabric. To effect this he proposes to subject the goods in the lye to great pressure. His apparatus (Figs. 13, 14, 15), consists of two vessels, or receivers, of a cylindrical form, made of tin or copper plates, and fixed upon one foundation. Into the larger of these, A, the materials are introduced through the opening at the top, and after that the cover, *d*, is firmly secured by the screw, I. A false perforated bottom, C C, placed in the interior of this cylinder, may be removed at will by the aid of a handle, *p*. All the air not retained mechanically, or in combination, passes off, during the filling of the cylinder with water through the pipe, O O O, at the bottom, by the pipe, *f*, which opens in the interior at the cover, *d*, and is joined at the other end to the indicator and regulator, H, in connection with the vessel, B. On a support, running across the top of this vessel, the pump, P, and its adjuncts are fixed; and this—by means of the suction pipe, *l*, perforated with small holes at *i*, so that nothing bulky can enter—forces the water through the pipe, *n*, and passages, O O O, into the vessel, A, containing the goods, and also into any others which may be in connection with it, as is shown by the continuation of the passage in the drawing. The pump has a safety-valve attached to it, as seen in Fig. 13 at *x*, weighted by the lever, S.

Fig. 15 is a sectional drawing of the regulator and indicator mentioned in the foregoing, and denoted by H. It contains a conical valve, a', which rising, presses against the lower end of the piston, c'; this works in socket, *d*, above which it has a collar, e', whereby it receives the pressure of the helical spring, f'; this causes it to butt against the top, b', screwed into the cylinder, and formed with a central opening for the passage of the piston-rod, c', graduated externally to show the degree of internal pressure; l' and i' show the corresponding parts in Figs. 14, 15. Before the air can escape, it must raise the valve, a', which cannot be accomplished unless the force determined by the adjustment of the spring is attained; hence it must escape by the pipe, *h*.

The operation is simple. The indicator is regulated so as to maintain a pressure inside the vessel, A, sufficient to expel the air, after which the material will be fit for the bleaching agents.

If it is desired to hasten the process of bucking the double kier patented by S. Barlow,* of Hakehill, near Middleton, is recommended. Fig. 16 shows the arrangement of these kiers. One of them, *a*, appears in section; *c* is a perforated bottom, upon which the goods to be bucked rest; the pipe, *k k*, connects the bottom of the one vessel, *b*, with the top

Fig. 15.



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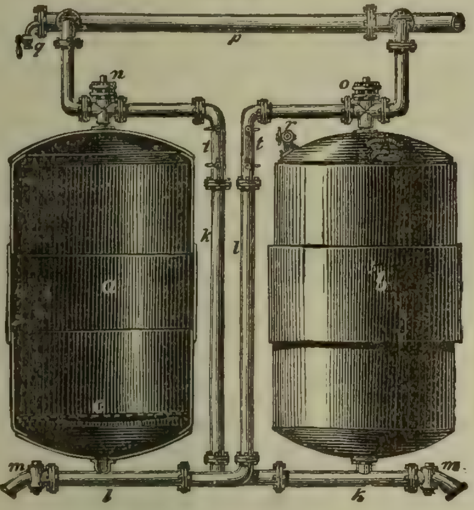
* His construction is essentially the same as that patented by him and J. Pendlebury in 1853.

of the other, *a*; pipe, *l l*, leads from the bottom, *a*, to the top of *b*; *m m* are taps, through which the spent liquor, &c., may be drawn off from the kiers; *n* and *o* are so-called two-way taps, by which the steam can be admitted into the respective kiers from the main pipe, *p*, and the reversing of which shuts off the steam communication, and admits the bowking liquor as it becomes expelled from the adjoining kier; *q* is a blowing-off valve; *r*, the pipe which brings the bowking liquor into the kier; *s*, the manhole (closed in the usual way by cross bars, secured by bolts and nuts), through which the goods are introduced and removed; *t t* are gauges by which it is ascertained when the liquor has passed from one kier and has entered the other.

Fig. 16.



The process, one of the shortest and simplest, is as follows:—

The goods are run through a trough, usually the washing trough, half filled with milk of lime; they are carried forward by winches, and deposited in the kiers by a boy, who enters the vessel to lay the piece in regular folds.

When the kiers are filled, a grid of movable bars is laid on the top of the cloth, and the manholes are closed. High-pressure steam is then admitted at the top; this presses down the goods and removes the lime water, which is run off at the bottom. At the same time the air in the interstices of the fabric will be displaced by steam. Milk of lime—40 lbs. of lime in 600 gallons of water—is now introduced into the first kier in a boiling state. High-pressure steam is again admitted, which forces the milk through the goods to the bottom of the kier, then up the tube, *l*, and on to the goods in the second kier. The steam tap of the first kier is now turned off, and the steam sent into the second. The same process occurs, and the liquor returns to the first kier. The whole operation is continued for about eight hours. Upon 3500 lbs. of cloth, 1 cwt. of lime is required.

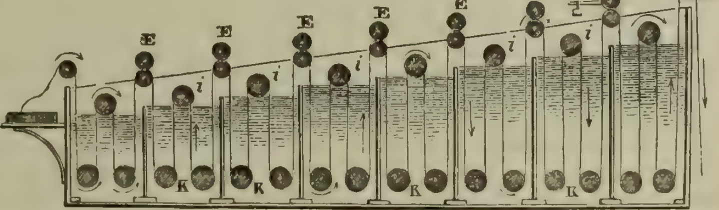
When the bucking with lime is completed, the steam pressure in the kiers is removed, the manhole opened, the grid taken away, and the cloth attached to the washing machine, which draws the goods out of the kiers, and washes them.

The apparatus is equally applicable for bucking with the caustic soda lye.

After the scouring has been completed, the goods are again washed, either in the dash-wheel or in one of the other machines for washing already described. The dash-wheel is very effectual, but requires skill in its management; for if its motion be slow, instead of the cloth being thrown against the opposite part of the wheel, it will slide down, and no detergent effect will follow; if, on the other hand, the movement be very rapid, the centrifugal force will cause the goods to circulate around with the periphery of the wheel, without ever falling against the sides as intended. Good results are obtained by twenty to twenty-two revolutions in the minute.

Where water is not in great abundance, the following arrangement (Fig. 17) has proved itself economical as well as efficient:—It consists of a number of vats of different depths, full of water, and supplied with a constant stream, which flows into the uppermost, and thence into the next, from this to the third, and so on till it reaches the lowest vat, whence it runs off, carrying with it the impurities of the scoured cloth. Within each of these vats or tanks guide and tension rollers, K K, are placed, and similar ones, *i i*, at the surface; the rollers, E E, are merely employed to squeeze the impurities out of the cloth as it passes out of the vat. Motion is communicated to the whole through the cylinders, A B and C D, which act also as squeezing and traction rollers, and are kept in close proximity by means of levers, *l l*. By the use of this machine a considerable quantity of cloth is washed in a very short time, but the tension to which it is exposed is so great that the pieces are considerably lengthened, oftentimes as much as 4 per cent. It is evident that, when very fine goods are operated upon, this cleaning machine will not answer.

Fig. 17.



Another apparatus distinguished by simplicity is that of H. Bridson, of Bolton-le-Moors, Lancashire. Fig. 18 is a longitudinal, and Fig. 19 a transverse section of the machine. The body of the *washer*, A, is a cast-iron tank, kept half full of water; through the sides of this tank two horizontal transverse shafts, B C, are passed, and carried on bearings in the two opposite side plates; they project from the side at B C, to carry corresponding spur-wheels, one of which is represented at E. By means of an intermediate driving shaft, which carries a wheel gearing into those upon B and C, the latter are moved in the same direction. B, C, have each a pair of discs, H I, Fig. 18, for holding the diametrically opposed parallel bars, J, which form the winces or revolving frames for acting upon the goods in the washing movement. The central shaft and wheel give motion to another superior wheel, K, fixed upon the axis of the lower roller, L, which, by moving in contact with another, squeezes the cloth. These rollers are of considerable size, and are supported by a pair of vertical standards, M, carried on a cross bar on the top of the cistern, which also bears a small standard for supporting the projecting end of the roller. The bottom roller is fixed, but the upper one is movable; means are furnished for adjusting them in the central vertical slot of the standard, M. In the longitudinal section, the course of the fabric, O, is shown round the guide roller, P, thence between the pair of nipping rollers, Q, set in bearings at one side of a division piece, R, and adjusted by handwheels and screws. After the cloth leaves these, it winds under the guide roller, S, and passes along between the first pair of vertical guide bars, T, then round the under side of the flat wince at the opposite end of the cistern; and returns in a parallel direction, moving in the same way over the bar, J J, of the discs, H I, and in the space between the second pair of division bars, T. In this way it continues its course, as seen in the transverse section, till it finally returns in contact with the wince bars, and passes up from beneath the guide-roller, U, set at the water level at the delivering end, over the external cylinder, V, and is delivered through the squeezing rollers, L, dry and clean. Two lines of fabric are operated upon at the same time, and therefore they follow the same course as that described.

The efficacy of this machine lies in the flapping or beating which the cloth receives from the revolution of the winces, during the time from its entrance till it passes out by V. This shaking and flapping or beating of the cloth on the surface of the water, and also the agitation of the lime immersed to bring it to the surface, have very great effect in detaching all the adhering impurities.

Fig. 18.

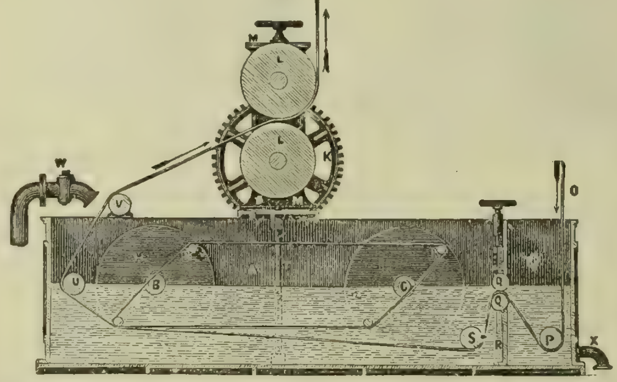
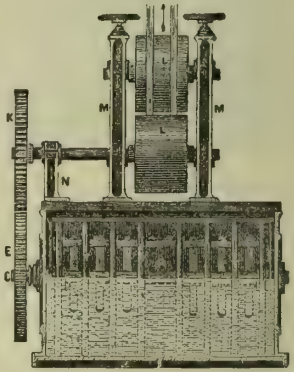


Fig. 19.



Souring.—This portion of the work, sometimes termed "chemicking," consists in immersing the goods, as they come from the preceding washing, in an acid solution. A gallon of strong sulphuric acid is added to 25 or 30 gallons of tepid water, and the whole agitated so as to intermix them thoroughly. This solution will have a density of from 1·047 to 1·040, and will contain from 6½ to 7 per cent. of oil of vitriol. Many persons employ a very much weaker acid liquor, but prolong the time of immersion; the above solution, however, will not injure the fabric; but if considered advantageous, a weaker souring-bath be used. If it succeeds in decomposing the lime soap, the certainty of having the whole of the sulphate of lime formed dissolved out by the weak liquor, is greater than if the solution were concentrated. The time during which the goods are permitted to remain in the acid or souring-bath is generally four hours; but this is varied by circumstances, such as those mentioned, or by similar ones. After the souring, the goods are passed on to the machine, to free them from any acid that may have adhered to them, and also from any sulphate of lime, or lime salts, formed by the acid used during the decomposition of the lime soap.

Scouring with Caustic Alkali, and Washing.—The cloth is next submitted to a bucking in soda lye, made by adding about 2 lbs. of crystallized carbonate of soda, or about three-quarters to one pound of the dry carbonate to milk of lime, and stirring in order to causticize it, allowing the precipitated carbonate of lime to deposit, decanting off the liquid, and mixing it with from 5 to 10 gallons of water, according to the strength of the liquor to be used. Although pounds are here mentioned, in the large bleach-works the operations are conducted on such a scale that cwts. of the alkaline carbonate are deprived of their carbonic acid; but the proportion of alkali in the bath for bucking the goods nearly always remains the same as above mentioned. It is customary, by way of improvement, to add about 40 lbs. of resin to every 100 lbs. of soda ash, and to employ this mixture diluted as above, but without separating the carbonic acid from the alkali as in the preceding The resinous soap thus formed is said to act with greater vigour upon the colouring matters and other impurities of the cloth than the alkali by itself, as it enters into a soluble double combination which is removed with facility. The period of boiling with this lye extends to eight or nine hours, and after this time it is submitted to the washing machine, till all the soap formed with the fatty acids and any traces of alkali are removed.

In case carbonate of soda and resin are taken, as described, the boiling is kept up during fifteen hours.

We have arrived now at the bleaching proper. The preceding operations have removed from the fabric the mechanical impurities, fats, and resinous bodies, and have thus rendered the fibre accessible to the influences of the bleaching agent. Bleaching powder is the substance which is now almost universally employed for destroying the colour of the fibre. (The composition and probable mode of action of bleaching powder will be considered under Chlorine.) On immersing the fabric in the solution of bleaching powder no decolorizing effect, or at least none worth speaking of, shows itself; but the subsequent exposure of the cloth to the action of an acid leads to the desired bleaching of the fibre.

Every acid is capable of producing this reaction, even the carbonic acid of the air; but exposure to the air for this purpose is now never resorted to, the process being far too slow; dilute sulphuric or hydrochloric acids are employed, since they decompose the bleaching compound rapidly and effectually.

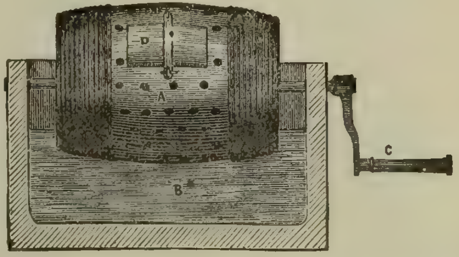
The question has frequently been raised whether it would not be more advantageous to use chlorine in the gaseous state. Past experience seems to be against it, but Persoz is decidedly of opinion that it would be preferable to employ chlorine in the gaseous state, since its bleaching effects upon the cloth would be exerted at once, without any of the subsequent processes and injurious effects upon the tissues, which are experienced when bleached by chloride of lime. He suggests a very eligible means for preventing its deleterious action on the workmen, by merely fitting up in the bleaching works a long funnel, which must be filled with chlorine gas; the pipe from the gas generator being introduced at the lower part of the funnel, so as to gradually displace the air. At the base of the funnel there should be a shallow vessel of water, to absorb any hydrochloric acid which may be formed. The pieces of cloth to be bleached might be introduced into the funnel through a slit made at the top of one of the sides; and by proper contrivances they would be made to circulate in the interior, so as finally to emerge at an orifice opposite to the entrance. Both these openings might be closed by water-lutes, to prevent any escape of the gas.

Bleaching with chlorine in water was also formerly practised; but both gaseous chlorine and its aqueous solution have long since given way to the much more convenient form of bleaching powder.

As bleaching powder does not destroy the colour of the fabric, it might be supposed that the immersion of the goods in a concentrated solution of it would not affect it injuriously; experience proves, however, that a piece thus impregnated, though at first not appearing to be injured, will very soon crumble into powder. The concentration of the bleaching bath is therefore of great importance. According to the strength and firmness of the goods to be treated, the density of the liquor ranges from 2° to 5° Twaddle; very fine fabrics are laid into very weak solutions.

The solution of the bleaching powder is effected in stone vats, wooden vessels being too rapidly attacked by it. To render its liquefaction more rapid and complete, a contrivance, such as that represented in Fig. 20, is employed. A cask, A, is partially placed into the vat, B, containing the solvent; it is traversed by an axis, at one of the extremities of which is a winch, C. The cask dips from 4 to 6 inches into the water in the vat, it is pierced with a number of holes, from one half to an inch in diameter, and contains a large opening, D, in one of its staves, closely covered over, serving for the introduction of the dry bleaching powder, together with some flints. The opening, D, being shut, the cask is put in motion by turning the winch, C, attached to its axis, and the flints or other pebbles, rubbing against each other, bray and pulverize the bleaching powder so as to promote its solution very rapidly. As it is of importance that the latter should be clear and transparent, it is allowed to rest till such substances as are held in mechanical suspension fall to the bottom. Without this precaution the goods are in danger of being seriously damaged, in consequence of the particles which are often found in commercial bleaching powder, and consisting of a basic chlorate, or some other compound not yet fully examined, being taken up in the cloth; these, when removed to the acid bath, will be decomposed with the evolution of so much chlorine or chlorous acid, or oxygen, as to produce holes in those places with which they had come into contact, the fibre being completely destroyed. Muslins, and such cloths as have an open texture, are very liable to this injury, if due care be not taken to prevent it. Schwartz refers to the chlorine disengaged from the compound as the cause of this; but Persoz differs from him, upon the ground that muslins may be exposed to gaseous chlorine, or to a clear solution of the bleaching material, without being in the least deteriorated. The latter chemist attributes the injury to the forementioned particles, having found that, if

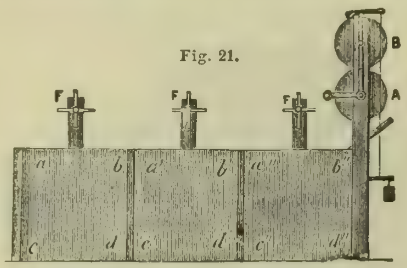
Fig. 20.



bleaching powder be washed till all soluble matters are extracted, an insoluble residue is obtained, mixed with more or less lime and carbonate of lime, which when treated with hydrochloric acid, generates one of the most energetic oxidizing bodies; and when this is spread upon the fibre, and then the latter immersed in sulphuric acid, it is burned in numerous places. The necessity of having a clear solution is therefore obvious.

Treating with Bleaching Liquor.—The strength of the solution being regulated, the cloth is thrown into loose folds and immersed in it for a period of six hours. After it is thoroughly saturated with the liquor it is abstracted and immersed in the steeping vats, where it is left for six or eight hours; after which it is introduced into the acid liquor, prepared so as to liberate the bleaching element to exert its influence upon the goods. This constitutes the ninth process. But instead of the preceding, many adopt a somewhat different course. Sometimes the cloth is placed in a copper boiler, similar to those described under scouring, and the bleaching liquor is passed through it in the same way that the lye is circulated in the bucking; this method, however, is objectionable, as the cloth is liable to be only partially decolorized; and it is exposed to the great danger of being injured by the boiler. The cloth is occasionally immersed in the solution for the proper period, and then left to remain exposed in the atmosphere of the room for some time, during which carbonic acid is absorbed, and the chlorine liberated to act upon the colouring matter of the cloth. After a certain time the goods are plunged into the acid solution, and here the whole of the bleaching element is set free. Again, many proceed by steeping a suitable quantity of cloth in a vessel adapted for the purpose, over which a roller is fixed. When the cloth has been immersed in the liquor for thirty or forty minutes, it is passed over the roller and suspended above the vessel till the solution ceases to drip off; it is then removed to the sulphuric or hydrochloric acid bath, over which it is hung, and the goods unrolled into the acid. Another process frequently resorted to is the following:—The cloth is placed for some hours in wooden troughs (Fig. 21) lined with lead, $a\ b\ c\ d$, $a'\ b'\ c'\ d'$, $a''\ b''\ c''\ d''$, which are filled with bleaching powder solution, and over which rollers, F F F, are fixed, for the purpose of communicating motion to the pieces, so as to increase their surface of contact with the solution. On withdrawing the pieces they are passed between the squeezing rollers, A B, placed on the side of one of the end vats, and the excess of the bleaching solution returns into the vat, $a''\ b''\ c''\ d''$, by an inclined plane which is immediately under the rollers.

Fig. 21.



When it is desirable to perform the bleaching rapidly or continuously, a concentrated solution of the lime salt is taken, sufficiently concentrated to destroy the fabric were it to remain in contact with it for any length of time; and into this the cloth to be operated upon is introduced for a certain period, prolonged or abridged according to the strength of the solution, and afterwards passed between a pair of squeezing rollers, again re-immersed and afterwards pressed, till the fibre gets thoroughly imbued with the liquor. At this period the cloth is thrown into the acid-bath for the purpose of liberating the bleaching agent; and as more chlorine is disengaged in this case than when the solution is weaker, the tank is covered over to carry off the excess of the gas, so as not to obstruct or injure the workmen.

The bleaching liquor must not be of too low a temperature; 70° to 80° Fahr. (21°·1 to 26°·6 C.) is found to answer best, since at this temperature the solution easily enters among the pores of the fabric, and yet does not injure the latter.

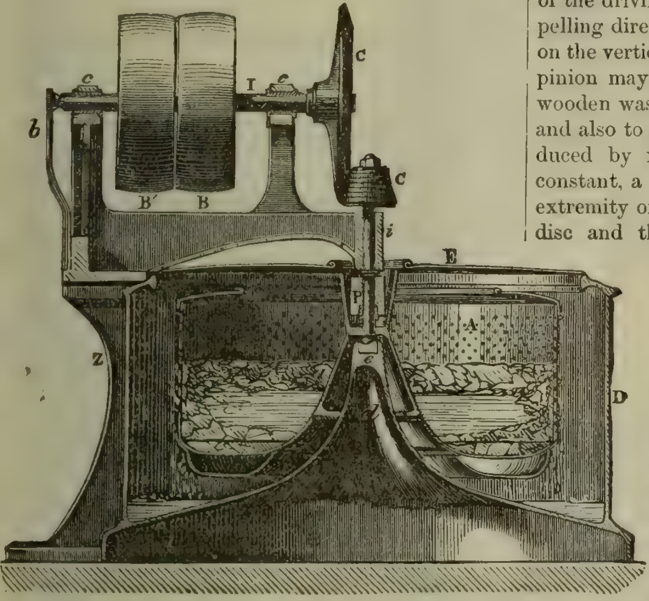
Souring.—The concentration of the acid-bath depends entirely on that of the foregoing solution; has the latter been strong, then the acid-bath too must be of considerable strength, and *vice versa.* As a rule, 20 to 100 lbs. of sulphuric acid in 3000 lbs. of water, form the limits of the strength of the acid-bath; but of course there are frequent exceptions. The goods are left for three to four hours in this bath.

Before proceeding to the steeping in water, the goods are often subjected to pressure. This operation has a twofold effect: it frees the fabric from any excess of bleaching liquor, and next, it puts the remaining portion of the bleaching solution into a more intimate contact with the fibre of the fabric. Whenever goods are meant to be brought into the press, the strength of the bleaching liquor may without risk be increased, and thereby the time allowed for the goods to remain in the bleaching bath be considerably abbreviated. A machine, specially adapted for the purpose, has been constructed by C. Mather and W. Platt. It has two cylinders of the largest possible dimensions, made of hard wood, or only the upper one of wood, and the lower one of a compressed textile fabric. The axles of the cylinders are placed in a frame so constructed that the axle of the upper cylinder can, by means of a screw and a lever, be so adjusted as thereby to increase or diminish the pressure of the upper cylinder upon the lower one. A small steam engine sets the lower cylinder into motion; the upper cylinder is moved simply by friction. The fabric passes through the machine between the two cylinders, and the pressed-out liquor returns through a funnel tube into the bleaching bath.

Steeping.—The goods come from this press, or sometimes directly from the acid-bath, into cisterns filled with clean water, and are allowed to remain there for ten or twelve hours, after which they are rinsed, in order to remove the lime-sulphate that has formed and settled upon the fabric in the two preceding treatments with bleaching liquor and the sulphuric acid bath. Part of the colouring matter attached to the fibre has by this time been eliminated; another portion has only been modified and still adheres, though now in a colourless state, to the fabric.

Bucking with Caustic Soda or its Carbonate.—To separate the decomposed colouring matter, the cloth is boiled in a lye of carbonate of, or caustic, soda during eight hours, in the same way as has been already mentioned: 60 lbs. of carbonate of soda, rendered caustic by maceration with quicklime and water at a boiling heat, is the quantity of alkali proportioned to 2100 lbs. weight of cloth; and also to every boiler of one ton capacity. After this operation has terminated, if the cloth is not sufficiently white, it is submitted to one, two, or three subsequent immersions in a bath of the lime solution, then in acid, and again washed and reboiled in the soda lye, till the proper decoloration has resulted. The density of the liquors employed diminishes from the first immersion, according as the cloth is depurated.

Fig. 22.



Souring (3rd).—The goods pass again through a bath of sulphuric or hydrochloric acid, to prevent the recurrence of a more or less yellow colour, contracted by the action of the air upon the resinous matter of the cloth, which is only temporarily decolorized. This substance is insoluble in alkalies, but is dissolved by acids with the aid of heat. Besides the effect of dissolving the resinous substances, any traces of metallic oxides, such as iron, alumina, or lime, which may be present, and unless removed would materially affect the printing of the goods, are so modified that they can be entirely separated in the subsequent washing to which the goods are submitted.

Washing.—The resinous matters, &c., dissolved in the course of the previous operation, as well as the adhering acid, are removed by a final washing, with which the series of bleaching operations is concluded.

Drying and Mangling.—The goods have now, before being submitted to sizing, &c., to be freed from the water, and this is done by centrifugal machines or by pressing in mangles. Fig. 22 represents a machine worked by centrifugal force, constructed by ROHLFS & SEYRIG. The driving shaft, I, mounted in the bearings, *c c*, of a standard fixed to the frame of the apparatus, and advancing to the centre of the top of the drum, A, carries two pulleys, B, B′, which are made to turn with great speed. The drum, A, must revolve at the rate of from 1200 to 1500 revolutions per minute. To the extremity of the driving shaft is riveted a conical disc, C, impelling directly by friction a conical pinion, C′, fixed on the vertical shaft which carries the drum, A. This pinion may be formed with leather, caoutchouc, or wooden washers, to prevent its being quickly worn, and also to avoid the noise which is commonly produced by rotation. That the pressure may be constant, a spring, *b*, is connected with the opposite extremity of the shaft, tending steadily to press the disc and the pinion against each other; a very smooth movement is thus obtained with perfect regularity.

The body, D, of the machine is connected by the binder, Z, with the basis or support of the apparatus, and at the same time with an interior enlargement, *d*, which sustains the socket, *e*, and the lower extremity of the pivot. The drum, or copper, A, which is attached to this pivot, and contains the goods to be operated upon, moves therefore along with it, and keeps itself in equilibrium, for it is placed in the same conditions as a balance; that is to say, the rounded pivot, P, is not encased in its support, and may assume all the positions due to the inequalities of the load being regulated by the force of rotation. The holes with which the drum is pierced, as shown in the figure, permit the water expressed from the goods by the powerful centrifugal action, to escape into the outer case in which the revolving drum is inclosed. The goods, when removed from this machine, are found almost perfectly dry.

Among mangling machines, that devised by MORE & SON of Glasgow is simple and highly effective. (Figs 23 and 24.) It consists of six rollers—three of compressed cotton, three of brass—fixed upon a cast-iron frame; the lowest roller is brass, the next cotton, and so on alternately. The pressure is applied to the rollers by a screw or lever on the top of the frame, and there is also another arrangement of levers for the three lower rollers, whereby the pressure may according to requirement be varied.

Fig. 23 is the end elevation, Fig. 24 a longitudinal view of the machine.

A. A. Bastaert, of Paris, dries the finished goods by submitting them in closed chambers to the action of a mixture of heated air and superheated steam; goods so treated are said to be peculiarly soft and delicate to the touch.

Starching.—When freed from moisture by either of these methods, the pieces could be considered as finished, if the custom of purchasers did not insist upon demanding a glossy appearance which fabrics of cotton fibre do not possess. To meet this wish the goods are starched. This expression is rather a misnomer, inasmuch as starch proper is never used, being far too expensive. Flour is the substance chiefly employed, but the additions it receives are sometimes so preponderating as to reduce the proportion of the flour to the merest fraction. Fine porcelain clay and ground slate are the most usual admixtures, and it is by spreading mixtures of these substances with flour and water upon one side of the fabric and subjecting it to strong pressure, that they are incorporated with the fibre. To improve the colour of the starching or sizing mixtures, a little indigo is added. The sizing and subsequent drying is accomplished simultaneously by a machine represented in Figs. 25 and 26:—A is the box containing the paste, which is used to starch or stiffen the goods; *a* is a winch, which can be employed to turn the machine by hand, although in large factories it is usually impelled by steam power; *b* is the driving pinion; *d d′*, two brass rollers with iron shafts, the lower of which is moved by the wheel, *c*, in gear with the pinion, *b*. The uppermost roller, *d′*, is turned by its friction with the other, which is pressed upon it by the weighted lever, *h*; *e* is the trough filled with the paste; it rests upon the bars, *f*, and may be placed higher or lower by means of the adjusting screws, *g*, according as the roller *d*, is to be plunged more or less deeply. A brass roller, *i*, serves to press down the cloth into the paste.

Fig. 23.

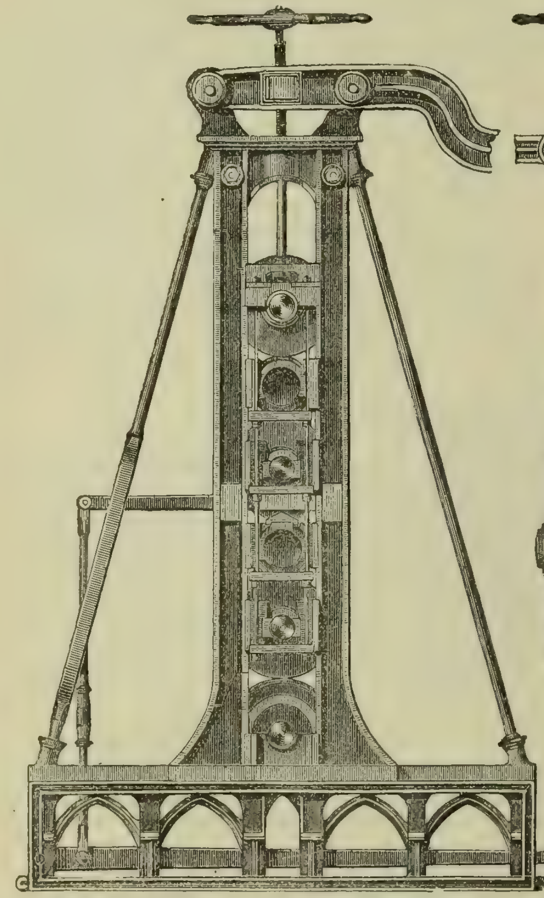
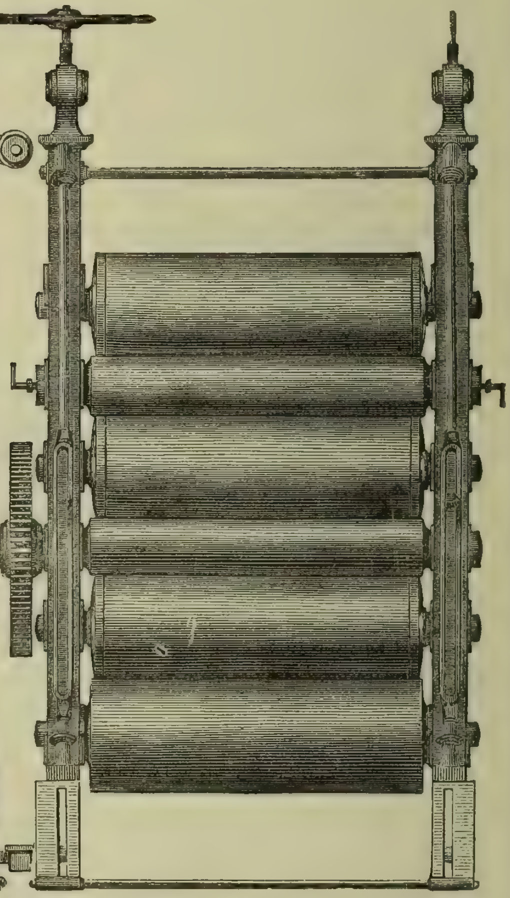


Fig. 24.



The drying portion of the machine is denoted by B. In this department, *k k* is the iron framing which supports the five drums, *l l l*; these drums are hollow copper cylinders heated by steam; *m m m* are small copper drums in pairs, turning freely on shafts under the former, for stretching and airing the goods during their passage through the machine; *n n* is the main steam pipe, from which small copper tubes, *o o*, branch off into the superior drums. There are similar main pipe and branch communications at the other end of the drums for discharging the condensed water, the pipes passing through air-tight stuffing-boxes. Whenever the steam becomes feeble, or it is necessary to turn it off, there are valves, *q q*, in the drying drums, which open internally to admit air, so as to prevent the collapsing of the cylinders, which the pressure of the atmosphere would occasion when they are exhausted; C is the cloth-beam from which the starching roller draws forward the goods; D are two rollers, of which the lower is provided with a band pulley or rigger, driven by a similar pulley fixed upon the shaft of the starching roller, *d*. These two rollers pull the goods through the drying machine, and then let them fall either upon a table or floor, as best answers. In this operation the cloth is either completely dried or left slightly damp, according to the wish of the operator: the former by communicating high-pressure steam to the drying drums; the latter by expediting the passage of the cloth, and introducing steam of a lower temperature.

Calendering, Folding, and Stamping.—The cloth passes over a sprinkling or damping machine, consisting of a circular brush, the tips of the hairs of which touch the surface of the water in a tank underneath; and by communicating a rapid motion to this brush, it discharges a shower of minute drops upon the piece as it is drawn from one end of the machine to the other. At first the moistening is partial; but after the cloth is permitted to remain in a heap for some hours, the dry parts absorb the excess of water from the wet spots, and the whole acquires a uniform dampness. The damp cloth is laid down in front of the calender—a machine greatly resembling the mangle represented in Figs. 23 and 24. It consists of a number of rollers running in a stout cast-iron frame, and pressed together by weighted levers; the rollers are fixed parallel one over another, and bear a wheel gearing on their shafts to make them revolve. The smallest two of these rollers are of cast-iron, well turned and polished, and the large ones are made of paper. The cloth passes between the rollers, and is received upon a cylinder called the "batching" roller.

Fig. 25.

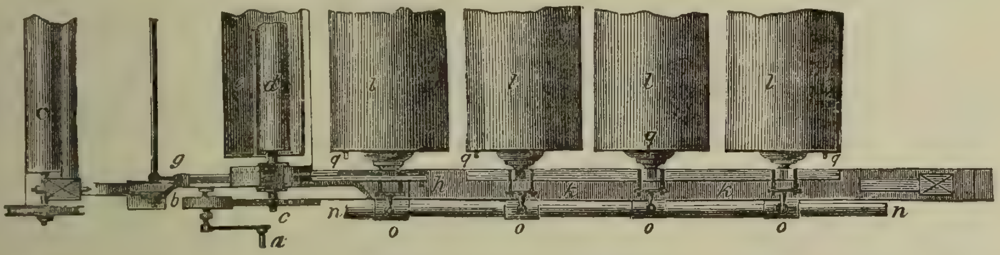
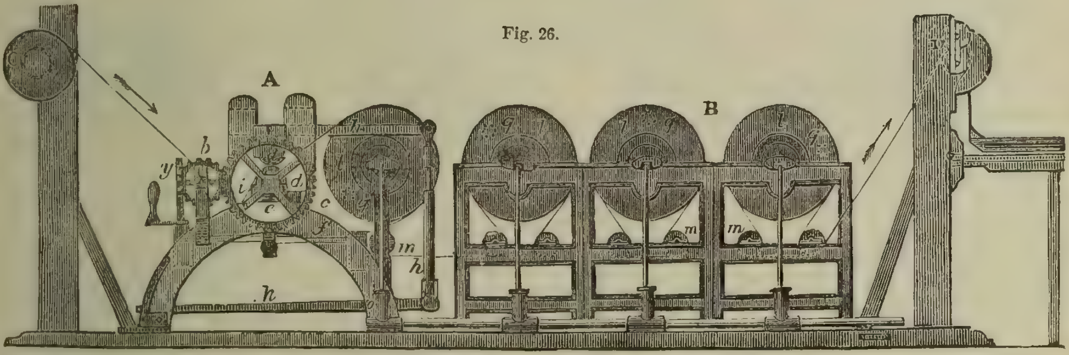


Fig. 26.



During the passage of the cloth over the rollers, its appearance is considerably changed. When it is drawn in a single sheet through the rollers, the threads are first flattened, but by going through the other rollers the fabric receives a peculiarly soft appearance. If, however, the sheets are double, or two sheets simultaneously are passed between the rollers, the threads of the one sheet make an impression upon the other, and both look wiry and hard. Through variations in the foldings, the appearance of the goods may be still further changed.

When the cloth has undergone all these operations, it is folded up, stamped with the pecular brand corresponding to the standard of the market at which it is to be disposed of, and is ready to be sent to its destination. Should the calico be intended for printing at home, the latter process of calendering is not applied, and sometimes the starching is dispensed with, as it is only required in this case to have the natural colour of the fibre of the cloth removed. It is customary, however, to stiffen the goods, as this affords certain facilities in printing them. After the starching the cloth is folded upon a roller.

The preceding description represents the leading features of the process of bleaching cotton fabrics; but in practice great variations are introduced in the order of the single operations, their duration, &c. It would go beyond the scope of this Dictionary to give anything like a detailed account of the variety of systems as now practised; but to show the difference in the methods of manipulation, a few shall be briefly sketched here.

The Grean Process.—*First stage—Scouring.*

(1.) Goods are immersed in a soda liquor of 2° (Gay Lussac) concentration (1 part of soda to 300 parts of water) during forty-eight to fifty hours.

(2.) Fulled and washed.

(3.) Treated for twenty-four hours with caustic soda of 12° strength.

(4.) Fulled and washed.

(5.) Placed for half-an-hour in a hydrochloric acid bath; 1 part of acid in 20 parts of water.

(6.) Fulled and washed.

(7.) Treated a second time with caustic soda, but of only 9° strength.

(8.) Fulled and washed.

(9.) Immersed in acid bath, as in (5.).

(10.) Third immersion in caustic soda lye, this time of 6° strength.

Second stage—Decoloration.

(11.) Immersion for three hours in bleaching liquor of 1°·5 of the chlorometer; repetition of this treatment for other three hours in a bleaching bath of 1°.

(12.) Treated with caustic soda lye of 4°, gradually raised to boiling, and maintained in ebullition for two hours.

(13.) Acid bath, as in (5.) and (9.).

(14.) Fulled and washed.

(15.) Immersion for three hours in bleaching bath of 0°·75 of the chlorometer.

(16.) Acid bath, composed of 1 part of hydrochloric acid in 300 parts of water.

(17.) Fulled and washed.

Grean was the first to lay down, as a principle, that the immersion of the fabrics in the bleaching solution should only take place when they are deprived of all fatty and resinous matters. His process is specially characterized by the fact that those impurities are gradually removed by repeatedly treating the goods with dilute lyes, and that the fabrics, after having been exposed to the action of the bleaching liquor, are first put into soda lye, and only afterwards into the acid bath; this treatment brings about the decomposition of the lime salt by soda, and the replacement of the lime by the latter.

The American Process.—*First Stage—Scouring.*

(1.) Bucking of the goods with lime from twenty to twenty-four hours. To 1000 pieces of cloth (three-quarters yard wide) 36 lbs. of fresh-slaked lime are taken, and instead of water, the residue of lye (3.).

(2.) Washing.

(3.) Repetition of operation (1.).

(4.) Washing.

(5.) Immersion in tepid sulphuric acid bath of 1° B.

(6.) Washing.

(7.) Bucking with soda carbonate: 2 lbs. of carbonate to every 1000 yards of fabric; residue of lye (12.) serves as solvent.

(8.) Washing.

Second Stage—Bleaching Proper.

(9.) Bath of bleaching powder, so dilute as to show no increase of density by the areometer, and to disengage no sensible quantity of chlorine on being saturated with an acid.

(10.) Hydrochloric acid bath of 2° B. strength.

(11.) Washing.

(12.) Bucking for twenty-four hours with carbonate of soda, 9 lbs. of carbonate for every 1000 yards of calico.

(13.) Washing.

(14.) Repetition of (9.).

(15.) Acid bath as in (10.).

(16.) Final washing and rinsing.

According to J. Tribelhorn and P. Bolley the hot bucking can be dispensed with by employing lyes containing stannic oxide. This oxide is obtained by adding soda carbonate to an aqueous solution of chloride of tin of 9° or 10° B. strength. The process is the following:—

(1.) Keeping the goods for twelve hours in tepid water.

(2.) Washing.

(3.) Immersion in a bath composed of 3 lbs. of the above tin preparation, dissolved in about 10 lbs. of caustic soda lye of 39° B., and diluted to 1° B. concentration.

(4.) Passing the goods through some mangling machine or press.

(5.) Sulphuric acid bath of 1° B. for half an hour.

(6.) Washing.

(7.) Immersion in weak bleaching liquor.

(8.) Steeping in sulphuric acid bath of 2° B. for three hours.

(9.) Washing.

(10.) Boiling with carbonate of soda solution of 1¼° B.

(11.) Washing.

If a high degree of whiteness is required the goods are further treated—

(12.) For four hours with bleaching liquor of ½° B.

(13.) Immersed in sulphuric acid bath of 1½° B.

(14.) Thoroughly washed.

In the "Continuous" system of bleaching the several operations already described are essentially the same; but the bath and other requisites are so arranged that the work may be continued regularly. The annexed sketch shows the general arrangement of the apparatus, as used by Graham, of Manchester, and from the perusal of the preceding details the whole will be readily understood.

Fig. 27 represents the arrangements. A is the boiler or kier, which may be similar to either of those described; B is the scouring machine; C, the souring and chemicking machine; and D, the steeping cistern. The course of the cloth from the boiler to the steeps, over the carrying winches, E E E, and through the various machines, is indicated by the line, F F F.

In Claussen's process the goods are first treated with carbonate of sodium, and then with the bleaching liquor; hypochlorite of sodium and lime carbonate are formed; the latter is decomposed in the hydrochloric acid bath, and is afterwards washed away as calcic chloride. When goods are to be dyed turkey-red, or in case of lime, Claussen employs hypochlorite of magnesia in the place of the ordinary bleaching compounds. The magnesia hypochlorite is prepared by mixing a solution of 2 parts of magnesia sulphate in 12 parts of water with one of 1 part of bleaching powder in 12 parts of water; sulphate of lime goes down, and magnesia hypochlorite remains in solution.

For goods which are to be printed with madder colours, or are to remain white, Higginbotham & Sons, of Glasgow, use the following modification of Claussen's process:—

Scouring.—Boiling for two hours in caustic soda lye of 1° T., to which 5 per cent. of quicklime has been added; soaking in soda carbonate of 2° T.; hydrochloric acid bath of 3° T.; washing.

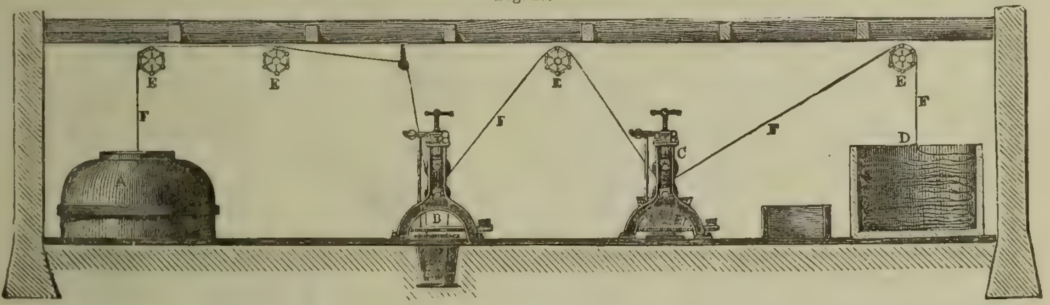
Bleaching.—Steeping in hot, but not boiling, soda carbonate liquor; immersion in bleaching bath of 3° T.; souring as before, and thorough washing.

Finishing.—Boiling half an hour in resin soap; immersing in the hot, but not boiling, bleaching liquor; acid bath as before, and final washing.

J. Higgins, of Manchester, has devised the following method of bleaching cloth:—About 3500 lbs. of cloth, after being singed in the usual way, are passed through a solution prepared by macerating about 224 lbs. of lime in a convenient quantity of water. When the cloth has been moistened uniformly with this liquid a further dilution with water takes place, and 2 or 3 gallons of bleaching liquor of 8° T. are poured in, and the whole boiled by steam for fourteen hours. After ebullition it is withdrawn, washed in water, and steeped in dilute sulphuric acid of 3° T., or hydrochloric acid of 2° T.; again washed with water, and folded in another kier containing a mixture prepared in the following manner:—Into an iron or other vessel put 30 gallons of water, 120 lbs. of soda ash, 80 lbs. of American resin or gum. Boil this compound by steam for eight hours, and then put in 25 lbs. of lime, made into a cream with water. Boil for six hours more and transfer to the kier, after which the cloth is folded in, sufficient water added, and the whole kept at ebullition for fourteen hours.

When the cloth is sufficiently boiled it is removed and washed with water, then steeped in or passed through a bleaching solution marking 5° on T. It is then passed through sulphuric acid 3° T., or hydrochloric of 2°, and afterwards well washed.

Fig. 27.



In some cases it may be well to give the goods another boiling in a kier with soda alone.

When goods have been "limed" in Barlow's double kier (see Fig. 16) they usually undergo the following process:—

After the bucking operation is terminated, the manhole is opened, the grid removed, and the cloth attached to the washing machine, which draws the pieces out of the kiers and washes them.

The goods are then passed by winches through the souring apparatus, or are soured by having hydrochloric acid of 2° T. pumped upon them. They must remain with the acid two or three hours, either steeped in it or after having passed through it.

A new washing follows, and the cloth is drawn by winches as before through the washing troughs back into the kier.

Steam is introduced into the kier, the air and cold water are expelled (by the tap at the bottom), and a solution of soda-ash and resin is poured into the vessel; 224 lbs. of soda-ash and 150 lbs. of resin in 600 gallons of water for 7000 lbs. of cloth. The kiers are then masked for about eight hours, as before, by driving the liquid alternately from one cylinder into the other. If the cloth is very strong, or if it has been printed upon in the grey state, a larger proportion of soda may be used.

Another washing follows, and then immersion in the bleaching solution, which has previously been warmed up to 80° or 90° Fahr. The strength of the solution is about $\frac{1}{2}$° T., or 1·0025 specific gravity. When the bleaching is for finishing white, milk of lime is added to the bleaching powder solution in order to retard the action.

The bleaching operation is followed by washing, souring, and so on.

If the cloth has been well managed, it will almost be white when it leaves the second kier treatment, and will therefore require very little bleaching. The method has the undoubted advantage of quickness; eight hours only of bucking appear sufficient, and the whole course of operations may be performed in two days.

In bleaching muslins, fermentation, almost entirely abandoned in all other cases, is the first step. The goods are allowed to remain in the lye for about thirty-six hours at temperatures varying from 100° to

150° Fahr. They are next bucked with potash and soap; for 112 lbs. of muslin, 6 or 7 lbs. of pearl ashes and 2 lbs. of soft soap, with 360 galls. of water, are employed, and ebullition is maintained during six hours; the goods are then washed by the scouring machine; after which they are rebucked for three hours, with 5 lbs. of pearl ash and 2 lbs. of soft soap; they are again washed, and afterwards immersed in a clear solution of bleaching powder of 6° on the indigo test tube, and allowed to remain in it for from six to twelve hours, when they are washed and steeped in dilute sulphuric acid, 3°·5 Twaddle. The cloth is next well washed and boiled in 2½ lbs. of pearl ashes, and 2 lbs. of soft soap, for half an hour; again washed and immersed in a bleaching solution as before, at a strength of 3° on the indigo test, and allowed to remain in it for six hours. After this the fabric is again washed and soured in sulphuric acid of 3° T., or spec. grav. 1·015. If the goods be strong, they will require another boiling, steeping, and souring. The sulphuric acid should be well washed out previous to the finishing operation with starch. Lime is occasionally taken for bucking muslins instead of alkali, the same proportion being used as above mentioned for the latter; the time of boiling, however, is not prolonged beyond fifteen minutes, lest the fabric might be injured.

From time to time attempts have been made to employ permanganates for bleaching purposes. TESSIÉ DU MOTAY and MARÈCHAL showed at the International Exhibition at Paris, 1867, goods bleached by permanganic acid. The bleaching liquor consists of a solution of an alkaline permanganate and magnesium chloride, in which the goods are left fifteen to twenty minutes. For 100 parts of the goods to be bleached 2 to 6 parts of permanganate of soda suffice. From the bleaching bath the goods pass into an aqueous solution of sulphurous acid, and are left there until all the oxide, which by reduction had been deposited on the fabric, is dissolved. The oxidizing and subsequent reducing operation is repeated until the goods have acquired the necessary degree of whiteness.

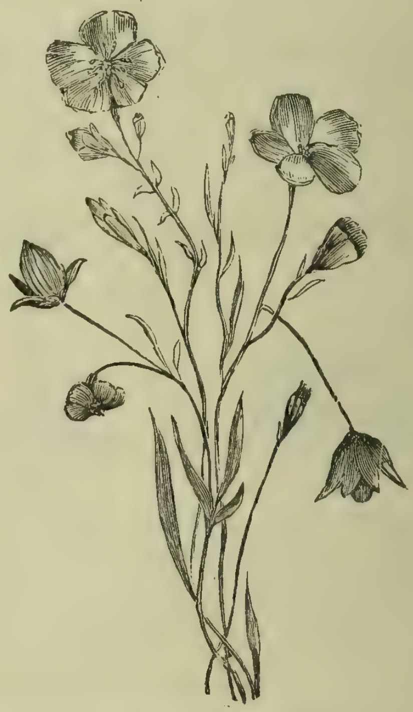
An important point in this method is the cheap preparation of the permanganate. The above-named French manufacturers take the manganic oxide, resulting from the immersion of the goods in the bleaching bath, fuse it with nitrate of soda, and pass atmospheric air through the molten mass; the manganate of soda which is formed is dissolved in water, and transformed through addition of magnesic chloride into permanganate.

Experiments conducted on a large scale in VERLAY's establishment in Comines (France) have shown that flax yarn is completely bleached by this process in twenty-four hours, and linen in only three days.

This rapid bleaching is, however, in the opinion of experienced bleachers, not trustworthy; it is suspected of affecting injuriously the fibre.

BLEACHING OF FLAX.—The bleaching of linen differs in many respects from that of cotton goods. Linen is manufactured from the fibre of the flax plant, *Linum usitatissimum.* (Fig. 28.) The plant is composed of three principal parts; the wooden centre, known by the term *shore* or *boon;* next to this the fibrous substance, which, when separated, constitutes the flax; and a thin outer membrane enveloping the whole. The fibres, when separated from the stem and the outer envelope, appear under the microscope as long, narrow, cylindrical, hollow tubes, not flat, and somewhat stiff. (See Fig. 2.) Their width averages from $\frac{1}{100}$ to $\frac{1}{150}$ of a millimètre. Tinctures of iodine and sulphuric acid colour it fine blue; concentrated sulphuric acid dissolves it. The flax plant has to undergo a peculiar treatment in order to separate the fibres from the stem and the envelope. The fibres are held together, and also firmly glued to the inner stem, by a kind of gum, the chemical nature of which is as yet very little understood. But the relation of this agglutinating substance to various solvents is tolerable well known, and this appears for practical purposes sufficient enough. Alkaline lyes readily dissolve the different compounds of which this gum seems to be made up, but they are nevertheless not applicable on the large scale on account of their being too expensive. A cheaper process, which, however, requires longer time, is resorted to for breaking up the gum. Among the bodies contained in the agglutinating substance there are found several forms of albuminous matter which bring about a kind of fermentation when the flax stems are left for some time in contact with water. This fermenting process, termed *retting,* is carried out in four different ways—cold water retting, tepid water and steam retting, dew retting, and mixed retting. Before the retting, the flax is submitted to

Fig. 28.



mechanical treatment, chiefly in order to remove the seeds, and in many cases also the roots; we do not propose to enter into this part of the process.

Cold Water Retting.—The raw flax is tied in bundles, after having previously been sorted according to length, the bundles are then placed in perforated wooden chests, or in a kind of lattice-work basket, and these are finally immersed in a pond, or a specially prepared pit filled with water. Retting in rivers, formerly practised to a great extent, is now avoided, since the flowing water carries off those constituents of the fibre which contribute to bring about the fermentation. The present mode of cold water retting is now almost universally carried on in pits of 4 feet depth, lined with brick or stone, and provided with a feeding and an outlet pipe for the water. The bundles, having the fibres with their roots to one end, are packed with the roots downwards into the chests, and are covered with boards weighted down so much with stone, as to keep the flax below water, but yet allow it to float. In the warm season the fermentation sets in very soon, and becomes apparent from the dark colour of the water and the disengagement of gas bubbles. A slow stream of water is now turned on and permitted to percolate the mass. An oversight in this matter leads easily to the destruction of the fibre — the fermentation of the glutinous substance passing into putrefaction of the fibre itself. In very hot weather, and still more when the atmosphere is charged with electricity, such changes may happen very suddenly. The operation, requiring, according to the season, from five to twenty-one days, is to be regarded as finished as soon as the central stem of the plant breaks easily between the fingers, and readily separates from the surrounding fibres. The flax is now washed, rinsed, taken from the pits, spread in thin layers upon a meadow, and left there to the influence of the air and the sun for several days. As soon as the surface appears dry, the stems are tied again at their upper ends, and spread with their roots in a circle, in order to give free access to the air. By this means the drying is sufficiently well accomplished; but sometimes the flax is piled up in heaps, which are covered with straw, and thus further exposed to the air.

The gases evolved during the fermentation—chiefly carbonic acid, but also ammonia, marsh-gas, and no doubt ammonium sulphide—are highly disagreeable and even injurious; the fishes perish in ponds in which retting operations are performed. To diminish the escape of these gases into the atmosphere, the bundles are taken from time to time from the retting pits, immersed in water containing ¼ per cent. of sulphuric acid, and then put back into the pit.

Dew Retting.—In this case the moisture of the atmosphere, in the form of dew and rain, is utilized for inducing and supporting the fermenting process.

The flax stems are spread in thin layers upon a meadow, and allowed to remain for eight to ten weeks. It is necessary in dry seasons to water the flax to prevent excessive drying.

Mixed Retting.—This is a combination of the foregoing methods. The bundles are left in the water until the beginning of the fermentation, and then spread in a wet state upon the meadow.

Steam Retting.—There are several methods for treating the flax with tepid water, and they all have that in common, that the vat containing the flax and the water is heated by steam introduced from a separate boiler. In SCHENK'S process the water is gradually brought to 80° Fahr., the admission of steam being regulated in such manner as to raise the temperature of the water every hour only by 1°, and in order to secure this the temperature of the liquid in the vat has constantly to be tested by a thermometer. When the fermentation is finished, which usually is the case after sixty-four to sixty-eight hours, the flax is washed by allowing water to enter at the bottom of the vat and permitting it to flow away through a pipe near the top; if the wash water were conducted downwards, the resinous impurities would remain between the flax bundles, these acting as a filter.

The following is the course of the fermenting process:—

(1.) Water colours brown, and gets gradually darker, without, however, passing into dark brown.

(2.) The liquor, which had for several hours remained clear, becomes turbid, and evolves gas bubbles of faint aromatic odour.

(3.) The evolution of gas becomes stronger, and a mass of scum covers the surface of the liquor.

(4.) Formation of a pellicle which conglomerates the scum bubbles.

(5.) Increased gas delivery, which breaks the scum pellicle at different spots, and sets it into wavelike motion. The gas contained in the large bubbles is without odour, and explodes when approached with a light.

(6.) Gradual decrease of the evolution of gas and the formation of scum; change in the odour of the gas, which, however, has not yet become unpleasant; increase in the formation of the mucous pellicle, which at the same time becomes darker.

(7.) Apparent cessation of the reaction. Quiet formation of a new, snow-white yeast-like scum, which breaks here and there through the pellicle, and, where it cannot do so, lifting it up, and thus giving the surface of the retting liquor an undulated appearance. Along with this the odour becomes exceedingly unpleasant. The fermenting process is now at its climax.

(8.) Pellicle continues to become darker, and the white scum disappears.

(9.) The pellicle commences to break up, so that the turbid brown liquor becomes more and more visible.

(10.) The torn pieces of the pellicle, as they float on the surface, begin to disappear; the process is finished.

The vats are often covered and provided with pipes for the drawing off of the unpleasant gases.

The drying of the retted flax is performed either by means of centrifugal machines, or the bundles are spread out flat, the fibres fastened in the middle between two wooden rods, and thus hung up in large airy barns, which are heated up to 100° or 110°, not more; in summer the temperature of the atmosphere suffices to dry the flax in about two days.

The flax is, after drying, stored away for six to eight weeks before it is submitted to the action of machines, in which the separation of the fibre, the flax proper, from the woody constituents is effected.

Recent experience has led back to cold retting; the operations are, however, carried on in vats which can be heated by steam, &c., but the temperature of the retting water is, as a rule, kept only at 70° to 80° Fahr. (21°·1 to 26°·6 C.).

That, however, the elimination of the impurities is more thorough in tepid water than in cold water retting is apparent from the following table, in which Hodges has given the result of his analyses of flax retted according to Schenk's method (1 and 2) and of flax retted in cold water (3). He found in 100 parts:—

	1.	2.	3.
Wax, resin, volatile oils, and acid,....	2·200	2·620	2·3
Sugar and colouring matter, soluble in alcohol,..........................	1·541	0·624	7·59
Gum and pectin bodies,.............	0·698	0·280	
Caseine and nitrogenous matter, soluble in water,........................	3·560	1·386	6·50
Nitrogenous matter, insoluble in water,	2·940	4·310	
Inorganic matter, soluble in alcohol,..	0·281	0·116	1·05
Inorganic matter, insoluble in alcohol,	0·076	0·044	
Inorganic matter attached to the fibre,	0·238	1·490	
Vegetable fibre,......................	87·974	89·136	82·56

Pownall subjects the flax, as it comes from the retting vats, to squeezing between iron cylinders, whilst he allows at the same time a stream of clean water to flow through the material. This operation removes adhering impurities, and also loosens the connection between the fibres.

Scrive proposes to interrupt the retting process every six or eight hours, and then to wash the flax in tepid water. This method is said to be advantageous, in so far as it brings about a more uniform action of the retting liquor upon the flax; but it requires large masses of warm water, and lasts considerably longer than Schenk's process.

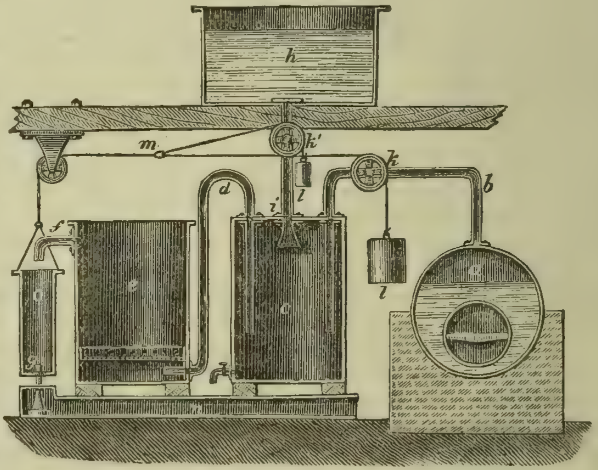
Tervangne adds finely powdered charcoal and chalk to the retting bath, in order to bind the gases evolved during fermentation.

Burton and Pye pass the flax through squeezing rollers before introducing it into the retting vats, and they submit it then to the action of water of 85° Fahr., to which some fuller's earth had been added, for thirty hours, press it out, and wash and rinse it with clean water, which is gradually raised to a temperature of 150° Fahr. After washing, the material is again subjected for four hours to a heavy pressure. This second forcing, as well as the first, is performed in the vat itself, which is cylindrical, and into which a circular board, touching the sides of the vat, fits.

Essentially different from all others is Watt's method, inasmuch as the flax is not made to undergo any fermentation. The flax is placed while dry in a cylindrical vessel, provided with a false bottom, and steam is passed into it from below; the steam condenses between the fibres and brings, in flowing down, the impurities with it. This steaming requires only twelve hours, certainly never more than twenty-four. After this preparation, the flax is passed through heavy rollers which deprive it of 80 per cent of the water absorbed during the straining; the remaining moisture is removed by drying the material under airy sheds.

Similar to the foregoing is Buchanan's method, but the apparatus employed differs from the usual constructions. The raw flax is placed in the retting vat, *e* (Fig. 29), which is provided with a perforated second bottom; an air-tight cylinder of equal capacity with the retting vessel, termed the "condenser," is connected with the latter through the pipe *c*, and with the boiler *a*, through the pipe *b*; the reservoir, *h*, contains cold water, to be introduced into the condenser through the pipe *i*, which ends in a rose. As soon as the condenser has been filled with cold water, steam is passed into the latter; when it has reached a temperature by which the steam can no more be condensed, the hot water will be driven by the steam into the retting vat, *e*, where it percolates upwards through the flax mass. The retting vessel and the condenser being of equal capacity; the former, partially filled as it is with the flax, cannot take up all the water of the condenser; the excess of water runs through the pipe, *f*, into the cylindrical vessel, *g*, which is suspended by the chains, *m*, and balanced, when empty, by the weight, *l*. In proportion as the cylinder, *g*, fills with water, it will sink, pull the chain which passes over the pulley, *k*, to the top of the steam pipe, *b*, and in so doing shut off the steam. At the same time another chain, joined to *m*, and passing over the pulley, *k'*, will open the tap of the water pipe, *i*, and allow cold water to shower into the condenser. The cylinder, *g*, in descending, reaches finally an iron rod, which, by being thus pressed, opens a valve in the cylinder, and allows its contents to run off through the pipe, *n*.

Fig. 29.



The sudden condensation of the steam produces a vacuum in the condenser, in consequence of which the water from the retting vessel will rush back. The cylinder, *g*, having become empty, is again pulled up into its original position through the weight, *l*, and causes thereby the chains to run in an opposite direction, and by doing thus, opening the steam tap and shutting off the water cock. The water in the condenser is again heated by the steam until the latter will no more condense in it; it will then be driven into the retting vat, and so forth. This operation is repeated ten to twelve times, and seldom requires more than four hours, after which the flax is in good enough condition for further treatment.

The drying of the flax is performed in the apparatus itself; all the water is let off through taps, and hot air blown through the retting vat; the air is heated in flues which are placed in the chimney of the boiler fire.

This process is distinguished by its being so wholly independent from manual labour, and also by its allowing great masses of raw material to be worked up in very short time; but its drawback is, that the same water is used repeatedly for the extraction of the impurities.

The process of bleaching goods made of flax resembles on the whole that of cotton fabrics, but it differs greatly in the details. It appears that the colouring matters of flax require repeated exposure to air and atmospheric ozone before they become so transformed that they can be destroyed by chlorine. Cotton goods may already after two or three washings and buckings be brought into the bleaching bath; but if such proceedings were adopted with linen, it would have the effect of rather fixing the natural colouring matter upon the flax, instead of removing it. The linen is therefore repeatedly treated with alkaline lyes, and between each treatment it is spread out on grass and left there for several days.

The proportion of impurities to be eliminated from the flax fibre is considerably greater than that of cotton; the latter loses in the whole of the bleaching operation about 5 per cent. of its weight, whilst the loss in flax amounts to 30 per cent. It has been tried, with a view to shorten the time required, to remove this large quantity of impurities by employing lyes of high concentration, but in all such cases the fibre itself proved affected. In the methods generally practised weak lyes are used in frequent repetitions; this makes the process of the bleaching of linen somewhat tedious, usually twenty to sixty days being required for it.

The following examples are intended to convey an outline representation of some of the most usual methods of linen bleaching:—

I. Irish method without croft bleaching.

(1.) Steeping in weak alkaline lye for thirty-six hours, and washing.

(2.) Bucking for six hours in a lye of 60 lbs. of caustic soda in 900 gallons of water, and washing.

(3.) Steeping for about fifteen hours in bleaching liquor, the strength of which varies according to the quality of the cloth, and then washing.

(4.) Immersion for six hours in acid bath (hydrochloric or sulphuric) of 3°·5 T., and washing.

(5.) Bucking for four hours in caustic soda, as in (2.), and washing.

(6.) Put for fourteen hours into bleaching bath, as in (3.), and washed.

(7.) Souring in sulphuric acid bath for ten hours, and washing.

(8.) Rubbed with brown soap upon a board, and washed.

II. Irish method with croft bleaching.

(1.) Steeping for thirty-six hours in weak alkaline lye, and washed.

(2.) Boiled with 60 lbs. of pearl-ashes (crude potash carbonate), washed, and exposed on the grass during three or four days.

(3.) Bucking with 80 lbs. of pearl-ashes, washing, and exposure on grass as before.

(4.) Bucking with 90 lbs. of pot-ashes (refined potash carbonate), washed, and crofted as above.

(5.) Bucked with 80 lbs. of pot-ashes, &c.

(6.) Bucked with 60 lbs. of pearl-ashes, &c.

(7.) Steeping in sulphuric acid bath, and washing.

(8.) Bucking with 60 lbs. of pearl-ash, washing, crofting for three or four days.

(9.) Immersion in bleaching bath, and washing.

(10.) Acid bath, washing, exposure on the grass.

(11.) Boiling with 30 lbs. of pearl-ashes, washed, laid out on grass.

(12.) Boiling with 20 lbs. of pearl-ashes, &c., as in (11.).

(13.) Acid bath, &c., as in (10.).

(14.) Rubbed with brown soap upon a board, washed.

The weights in the preceding two methods refer to the working up of 360 pieces of cloth, of 35 yards each.

III. Old Bielefield method, with exposure on grass, and without bleaching powder. Time required, fifty to sixty days.

(1.) Fermenting, fulling, and washing.

(2.) Exposing on the grass, with frequent watering, for three days.

(3.) Bucking five to six times successively, in caustic lye, by increasing temperatures from 135° to 195° Fahr., for six to eight hours.

(4.) Exposing, after preceding washing, upon grass, as in (2.).

(5.) Bucking and exposing on grass are repeated five times in succession.

(6.) Souring in a bath containing 1 part of concentrated sulphuric acid, or two parts of hydrochloric acid of 22° B., to 100 parts of water. In winter the bath is slightly warmed. The goods remain in it for six hours, and are then washed.

(7.) Bucking as in (3.), but with the temperature raised to about 205° Fahr.

(8.) Crofting as in (2.).

(9.) Rubbing with soft soap.

(10.) Bucking as in (7.).

(11.) Exposing on the grass for two days.

(12.) Bucking as in (7.).

(13.) Exposing as in (11.).

(14.) Souring in a bath of whey, or sour milk, for eight to ten days, and washing.

(15.) Exposing as in (11.) and (13.).

The last two operations, (14.) and (15.), are, if necessary, repeated until the goods have acquired the required degree of whiteness.

IV. German method for quick bleaching. Time, six days.

(1.) Fermenting, fulling, and washing.

(2.) Boiling for two hours in moderately strong caustic potash, fulling, and rinsing.

(3.) Steeping for four hours in bleaching solution of 2° B., and washing.

(4.) Sulphuric acid bath and washing.

(5.) Exposing on grass for twelve hours without watering.

The process is repeated in this order until the desired whiteness has been obtained.

V. Quite recently C. Hartmann of Heidenheim, has described a process which is said to yield a white of the highest quality. The course is the following:—

(1.) Steeping for forty-eight hours in water of 80° to 90° Fahr., and washing.

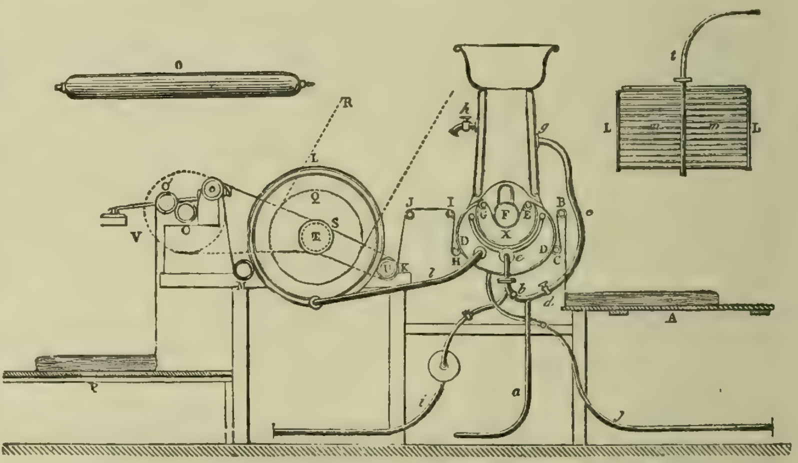


Fig. 31. Fig. 30. Fig. 32.

(2.) Drying in centrifugal machines, or otherwise.

(3.) Boiling for four hours in caustic soda of $2\frac{1}{2}$° to 3° T., and washing.

(4.) Drying.

(5.) }
(6.) } Boiling in caustic soda, as in (3.) and (4.).

(7.) Immersion in bleaching bath of hypochlorite of soda of $\frac{3}{4}$° to 1° T., for ten to twelve hours, and washing.

(8.) Exposing on the grass for eight days.

(9.) Bucking with caustic soda, &c., as in (3.)

(10.) As in (8.).

(11.) As in (7.).

(12.) Crofting for four to six days.

(13.) }
(14.) } Bucking, &c., as in (3.) and (4.).

(15.) Bleaching bath, &c., as in (7.).

(16.) Weak sulphuric acid bath, and washing.

(17.) Drying.

It is peculiar in this method that there is only *one* souring to three immersions in the bleaching bath.

VI. Chevalier Claussen employs magnesia sulphate for bucking purposes, and magnesia hypochlorite solution for bleaching. The process is the following:—

(1.) Boiling for two or more hours in caustic soda of 1° to 2° T.

(2.) Steeping in magnesia sulphate solution of 40° T.

(3.) Steeping in carbonate of soda solution.

(4.) Sulphuric acid bath of 2° T.

(5.) Washing.

(6.) Boiling with soda carbonate.

(7.) Immersion in magnesia hypochlorite.

(8.) Steeping in soda carbonate.

(9.) Acid bath as in (4.).

(10.) Washing.

(11.) Boiling half an hour in solution of resin soap.

(12.) Steeped, not too hot, in magnesia hypochlorite of 2° T.

(13.) Acid bath as in (4.) and (9.).

(14.) Washing.

In Bouchard's continuous process, the pieces are attached to one another endwise, and carried by rollers to a double metallic casing, heated by steam; from this the cloth passes into a steam-bath, and emerging from whence, it passes round the opposite corresponding part of the double metallic casing, and is then smoothed in its course over different rollers. It is dried and dressed by its passage over a great part of the surface of a drum or cylinder of large diameter, which follows the preceding series of rollers; this large double-cased cylinder or drum is heated by a current of steam. The cloth, by embracing its circumference, is dried and dressed; and these operations are completely finished by the passage of the goods over other rollers, and between a pair of squeezing cylinders. After undergoing this pressure, which is the last operation in the process of scouring, the cloth is deposited on a stretching table, as at first, on which it is folded and put up.

Fig. 31 is a longitudinal section of the machine employed; it measures about 6 feet in width, to adapt it to cloth of all sizes.

The goods in one long web lie on the table, A, placed on the right of the machine. In the first place the cloth passes round the roller, B, then descends round the inferior roller, C, and rises again bearing on the outer surface of the double-cased reservoir, D. The goods then continue their progress, passing round the roller, E, and the cylinder, F, from which they ascend to the roller, G, and again, in descending, bear on the opposite corresponding surface of the double-cased vessel, D. Leaving this, the cloth is conducted round the roller, H, and then, round the rollers, I J K; thence it proceeds round the large double-cased drum, L, and then from the larger roller, M, it rises to the upper roller, N, and finally passes between the squeezing rollers, O O′, from which it is again laid down on a stretching table, P, at the end of its course.

In this mechanical contrivance, the continual taking up of the cloth results from the transmission of the movements in the following manner:—Q is a pulley, which by the strap, R, receives motion from the prime mover. From the axis of this pulley the motion is communicated to the roller, K, and to the squeezing cylinder, O, by means of the pulleys, S T U V. Thus the continual taking up of the cloth is effected by the roller, K —and when necessary, by the roller, M—and by the squeezing-roller, O; the pressure of the upper roller, O′, on the inferior one, is regulated by a weighted lever. One of these squeezing rollers is represented in Fig. 32.

The steam is admitted into the double-cased vessel, D, by the pipe, *a*. This pipe is connected with two branches, *b* and *c*, the former being fitted with a stop-cock, which serves to allow the steam to enter the cylinder, *e*, at pleasure; this cylinder is perforated over a part of its lower circular surface, and in its whole length, with small holes, so as to force the steam from the cylinder to pass within the double casing by these holes. The steam thus introduced into the vessel, D, first heats the outer case, then penetrates into the interior, X, in which are placed the hollow metal rollers, E F G. This concavity is a steam-bath, to which the steam passes by small holes perforated at its base; it is here that the goods are submitted to the penetrating action of the steam. From this basin, which occupies the whole extent of the reservoir, D, the steam issues into the iron double-cased chimney, *g*, to escape upward.

The steam likewise arrives into the casing, *g*, by the branch, *c*, which is also furnished with a stop-cock, *d*; and it maintains the elevated temperature of the chimney, which is fitted with another stop-cock, *h*, required for working the apparatus. On the side opposite to that at which the steam enters, it issues out by the return pipes, *i* and *j*, to be again conveyed in any direction.

The large double-cased drum, L, is supplied with steam by the branch, *l*. This drum consists of an outer casing of copper and an inner cylinder of cast-iron; it is furrowed with circular grooves or channels, *m*, over its whole length, as represented in the horizontal section, Fig. 33; there is likewise a longitudinal canal, which communicates with all the circular channels. By this arrangement the steam circulates equally within the double casing, so as to diffuse the heat perfectly over the whole circumference, and throughout the entire extent of the surface. The steam escapes by the pipe, *t*, from the side opposite to that by which it entered.

TESSIÉ DU MOTAY'S permanganate process has already been described.

The preceding description of the retting and bleaching of flax applies also closely to the treatment of hemp, the fibre of *Cannabis sativa*, a plant belonging to the family of the *Urticæ*.

Besides cotton, flax, and hemp, there are yet several other vegetable fibres which enter into the formation of textile fabrics. The operations required for their purification and bleaching differ in no essential part from that of flax; as a rule the lyes and the bleaching liquor used are of greater concentration. The principal fibres of this class are China grass (*Urtica nivea*), jute (*Corchorus capsularis*), both of which are imported from India, New Zealand hemp (*Phormium tenax*), Manilla hemp (*Musa textilis*), and the cocoa-nut fibre.

BLEACHING OF WOOL.—Wool is composed of very fine filaments, the external surface of which presents the appearance of transverse corrugations. Under the microscope (Fig. 31), each fibre appears as a nest of thimbles, one within another. Wood fibre is covered with a greasy matter, termed *yolk*, or *suint*, derived chiefly from cutaneous perspiration, but secreted partly by the pores of the wool itself. CHEVREUL found two kinds of fatty matter in wool suint; the one, called by him *stearin*, melts at 140° Fahr., and requires 1000 parts of alcohol for solution; the other, *elaierin*, melts readily at 55° Fahr., and dissolves in 143 parts of alcohol. None of the two are said to saponify. The same investigator found merino wool to contain.

Suint soluble in water,	32·74
Earthy matter precipitating itself from the aqueous solution,	26·06
Fatty matter soluble in alcohol,	8·57
Earthy matter fixed by the fat on the wool,	1·40
Wool fibre,	31·23
	100·00

The removal of this suint is the aim of the preliminary treatment to which the wool is subjected before the bleaching process is resorted to.

The older method, still used in many places, consists in immersing the wool, packed into a net, in a slightly warmed bath of putrid urine, about 1 part of the latter to 5 parts of water. When the wool has become thoroughly soaked with the liquor, the net is taken out, suspended for a short time over the bath, and then placed into a vat, through which a constant stream of clean water runs. It is important to avoid the stirring of the net in the urine bath, in order to guard against the wool fibres getting twisted into a felt. The same bath serves several charges of wool.

The effective constituent of the urine is the carbonate of ammonium, which results in the putrefaction from the decomposition of the urea. The ammonium carbonate is not capable of saponifying the fatty matters, but it forms an emulsion, which will mix with water.

Carbonate of soda solution was tried in the place of the above bath, but was not found to answer; if, however, soap is used along with soda carbonate, very good results are obtained.

In 1857 CHEVREUL published a new analysis of the suint of wool, from which it appeared that the suint contained considerable quantities of potash salt. This observation led MAUMENÉ and ROGELET to patent a process for the recovery of the potash salts, and this process implies some modification of the scouring of wool. The material is thoroughly exhausted with water before it is submitted to the scouring with soap and soda carbonate solution.

Quite recently various solvents have been proposed for extracting the fatty matters. Bisulphide of carbon is found effective enough in bringing almost the whole of the fat into solution; but it seems to affect the fibre, to make it stiff, and impart to it a dark colour. It is reported, however, that a large establishment in Pomerania obtains satisfactory results by the use of this detergent.

Decidedly more successful is the process of P. TOEPLER & CO., in which impure amylic alcohol, ordinarily known as *fusel oil*, is employed for dissolving the fatty substances. The wool, previously exhausted with cold water, is treated in a tank with fusel oil, passed into a second tank filled with the same agent, and lastly washed with water, whereby the adhering oil is removed, such oil being slightly soluble in water. The wool is then freed from water by a centrifugal machine, or pressure in rollers, &c., and completely dried by exposure to a current of slightly warmed air.

The advantages of this process are said to be—

(1.) A larger yield of cleansed wool, the gain being almost 5 per cent.

(2.) Less "waste" in the subsequent operations of carding and spinning, and considerable lessening of the quantity of oil required.

(3.) From a given quality of wool, manufactured goods are produced which have the appearance of goods of a higher quality of wool, such wool being cleansed by the ordinary process.

(4.) With a given amount of plant, a larger quantity of spun wool can be made, as the carding engines, &c., require less frequent cleansing.

There are, however, two drawbacks to the use of this solvent. One is the great objection entertained by the neighbourhood, and sometimes the workmen themselves, to the use of great quantities of fusel oil; for though the vapours do not appear to be injurious, they are yet sufficiently unpleasant to make them intolerable. The second disadvantage is that unavoidable loss of oil must ensue in the operations, though the greater part is regained.

Caustic baryta and strontia have been adopted by DAUDENART and VERBERT, of Brussels, as substitutes for soda carbonate. The value of this process rests chiefly upon the cheap production of the cleansing agents.

One thing must be particularly guarded against in scouring wool or woollen goods, namely, the application of an elevated temperature, as it would affect the fibres, and cause them to felt more or less; the most favourable temperature for the scouring liquors is 60° to 65° F.

In scouring woollen goods it is imperative to keep them stretched during the time they are passing through the scouring liquor, otherwise they will contract unequally, and such shrinking will, of course, disfigure their appearance.

Fig. 30 represents a machine employed for that purpose. A A is a wooden frame-work; B, a vessel containing the weak lye or soap liquor for scouring the cloth; C C, two copper rollers which keep the cloth stretched, and at the same time deprive it of water; they are covered over with several folds of calico or paper, the better to express the moisture as the cloth emerges from the bath. The upper roller is provided with a lever, D, and counterweight, for increasing the pressure at will. E is a movable roller, working in a groove, on which the goods are wound, and which is intended to stretch them with greater or less force, according as the weight at the extremity of the lever, F, which is in contact with it, is made to act. G is a widening guide, with diverging grooves, to stretch the fabric before it arrives at the rollers, and prevent folding or overlapping. *a a a a* are small wooden cylinders, resting upon copper bearings; by these the goods are made to circulate in the lye for a certain time.

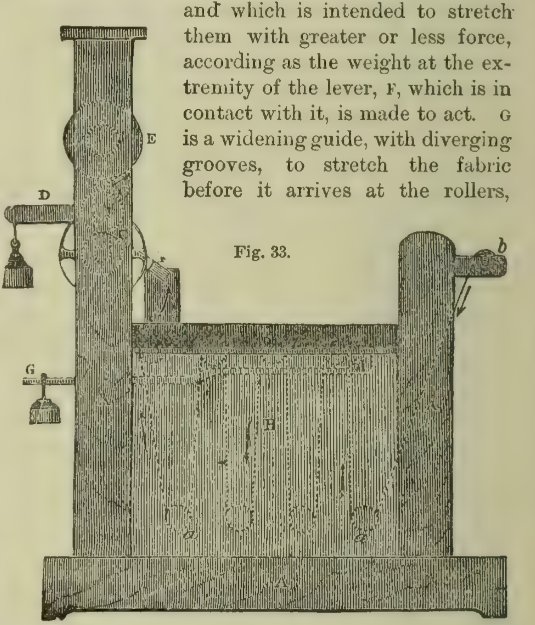


Fig. 33.

After the cloth is sufficiently impregnated with the lye, it is passed round the cylinders *a a a a*, and fixed—four, six, or more pieces, according to their length—over the cylinder at the point *b*. The working of the machine is carried on by putting one end of the web of cloth in communication with the traction rollers, *c c*, the remainder being passed into the vessel filled with warm water, and after circulating there for a certain time, coming to the squeezing rollers, C C, where it is divested of the most part of the liquid, and then folded upon the roller, E. After this the cloth is removed, to undergo either a new lixiviation or washing. When it is necessary that the last traces of the impurities of the filaments should be removed, the goods must be repeatedly transmitted through the carbonate of soda lye, alternated with an immersion in a bath formed of carbonate of soda and soap.

Claussen uses a feeble solution of caustic soda for scouring, and when the fatty matter from the wool has formed a soapy liquid, he gradually and cautiously adds small quantities of caustic soda, so as always to have the scouring bath a little caustic. After this the wool is saturated with a solution of carbonate of soda, put in a weak sulphuric acid bath, and finally washed. For very fine qualities of wool, carbonate of ammonia is used instead of carbonate of soda.

The agent employed for bleaching wool and woollen fabric is sulphurous acid, and not bleaching powder. Sulphurous acid unites with the colouring matter of the wool to form a colourless compound, which remains adhering to the fibre. Bleaching by means of sulphurous acid is termed "sulphuring."

The acid is applied either in the gaseous state, or in aqueous solution. When employed in the gaseous state, a large chamber is provided, the door of which closes hermetically; this chamber is furnished with valves and openings for supplying the air, as well as for the admission of the ignited sulphur; there is also a series of strong upright planks fixed in couples at proper distances from each other, and studded with pegs, the extremities of which are enlarged, and have a notch near the end, in order to prevent the cloth which may be strung upon them from falling off. All the pieces of cloth being stitched together so as to form one length, it is passed round these pegs, being carried alternately from one to the other in a horizontal course. When the cloth is fixed upon all the pegs of the frame, the chamber is hermetically sealed, and the burning sulphur introduced by the openings at the base; these are immediately closed, and the combustion of the sulphur is carried on merely by means of the air contained in the chamber. When this is exhausted, the burning of the sulphur ceases, but the interior of the chamber is charged with sulphurous acid gas, which is taken up by the moisture of the cloth; and, being thus brought in contact with the colouring matter, as it insinuates itself into the pores of the fabric, it exerts its bleaching powers very effectually. It requires about twenty-four hours' contact with the cloth before all the colour is destroyed; and sometimes the air has to be renewed, and a fresh quantity of sulphur burned, before the work is completed.

The next method by which woollens may be bleached, is by employing the sulphurous acid in a state of solution in water; its action in this state is more regular and economical than when used in the gaseous state.

The gas is easily and economically prepared by heating sulphate of iron and sulphur to low redness in a close cylindrical vessel of earthenware; an exit pipe at the end of the cylinder would convey the gas to a vessel adjoining, which may be filled with moss or some porous matter that will not absorb the gas, but clear it from any impurities which may be carried off mechanically; thence the gas could be conducted to the water cistern where it is to be absorbed, and admitted into it till the solution is saturated. To insure the complete impregnation of the water, the gas, as it makes its exit from the cistern filled with moss, &c., above mentioned, could be admitted at the base of a tower of convenient height filled with small stones, pieces of earthenware, and the like, through which a stream of water may be allowed to percolate from a cistern at the top, by a series of small perforations in the upper slab of the tower. This water meeting the ascending current of gas would completely dissolve it, and flowing out into a proper receptacle at the base, could be drawn away as use required. Water absorbs, at the ordinary temperature and pressure, about forty times its volume of the gas, part of which it retains even after continuous boiling.

The liquid, when submitting the cloth to its action, should have a temperature of between 80° and 90° Fahr. (26°·6 to 32°·2 C.); but if the solution is completely saturated at a temperature of 60° Fahr. (15°·5 C.), then, if it were elevated to the above point, a large volume of the gas would be expelled, and prove a powerful obstacle to the success of the operation, besides involving so great a loss of labour and materials; to avoid this, all that would be required is to dilute the liquor, so that nothing appreciable will be evolved. The goods being immersed into the bath of liquid acid, are retained there till such time as by an examination they are found to be thoroughly bleached; they are then taken out, washed well with water, and, if deemed necessary, with a little potash or soft soap.

The following is an enumeration of the operations to which woollen stuffs are subjected during the bleaching. Forty pieces of cloth, of 45 to 50 yards in length, are taken and stitched endwise together; they are then singed as cotton goods, and treated as here described:—

(1.) Immersed three separate times in a bath, formed by dissolving 24 parts of carbonate of soda and 6 lbs. of soap in 120 to 140 galls. of water, heated to 100° or 105° Fahr. (37°·7 to 40°·5 C.) After each passage of the goods over the roller, the activity of the bath is renewed by adding from ½ to ⅝ of a pound of soap to it.

(2.) Washed twice in clean water heated to the same point as the bath.

(3.) Transmitted three successive times through another solution the same as above, but without any soap: after each passage, except the last, ½ to ⅝ of a pound of soda is added to the liquor.

(4.) Exposed for twelve hours to the vapour of sulphur in the apparatus before alluded to, where 24 lbs. of sulphur are consumed for the decoloration of 40 pieces.

(5.) Passed three times over the rollers, as in the foregoing, in a bath in which 30 lbs. of soda crystals are dissolved in the same quantity of water as in (1.); this bath stands at 120° or 125° Fahr. (48·8 to 51°·6 C.), and after the first and second courses of the cloth through the liquor, a little more than ½ lb. of crystals of the alkaline carbonate is added to it.

(6.) Again bleached in the sulphuring chamber, as in (4.).

(7.) Immersed in a bath in which soda crystals are dissolved, as in (5.).

(8.) Washed twice in water heated to 105° F.

(9.) Sulphured for twelve hours.

(10.) Washed twice in tepid, and once in cold water.

(11.) Tinged blue by passing the goods through a liquid impregnated with a mixture of indigo and carmine, or acetate of indigo, to suit the operator.

These, and similar methods of procedure, are usually adopted in the bleaching of woollen fabrics; but when there is a large amount of greasy and resinous impurities united with the filaments of the cloth, and it is intended for delicate colours, the scourings are not sufficiently effectual in freeing it from the last traces of those bodies which operate so injuriously in the dye-bath.

The following process is particularly adapted for goods intended for very delicate printing.

After ironing and washing with water, the raw fabrics are—

(1.) Passed twice through an alkaline soap bath, heated to 140° or 150° Fahr. (60° to 65°·5 C.), and composed of 44 lbs. of crystals of carbonate of soda and about 9 lbs. of soap in 120 or 140 galls. of water.

(2.) Rinsed in warm water.

(3.) Passed twice into a bath formed of 22 lbs. of soda crystals, and heated to the same degree as in (1.).

(4.) Rinsed in warm water.

(5.) Passed into the sulphuring apparatus for ten hours, using 22 lbs. of sulphur for each 250 pieces.

(6.) Rinsed in warm water.

(7.) Passed twice into a bath containing about 15 lbs. of soda crystals, and heated to 140° or 150° Fahr. (60° to 65°·5 C.).

(8.) Passed twice into a bath containing 12 lbs. of crystallized carbonate of soda, and heated as before.

(9.) Rinsed in warm water.

(10.) Passed into the sulphuring apparatus, using this time 15½ lbs. of sulphur.

(11) Passed into tepid water.

(12.) Passed into a blue bath.

Bisulphite of soda solution is frequently used in bleaching fine qualities of wools, and to remove the yellow tinge imparted to the goods the usual blue bath is applied. J. B. Frézon, of Paris, treats the bleached goods, before putting them into the blue bath, with an aqueous solution of oxalic acid and salt, about 1 lb. of the acid and the same weight of common salt to 30 galls. of water. The fabrics are left about two hours in this solution, then washed and put into any of the usual blue liquors. This intermediate treatment is said to heighten the whiteness of the goods, and subsequently to facilitate the dyeing.

Alkaline cyanides have of late years been proposed for scouring wool; but whatever the merits of these agents may be, there is no doubt that the use of such poisonous substances is connected with too much risk ever to become general.

According to a French patent (Sanial & Beroujon, Lyons) woollen goods may effectively be scoured by steeping them in dilute solutions (about 2° B.) of alkaline sulphides.

BLEACHING OF SILK.—Silk is the produce of the caterpillar of the silk moth (*Bombyx mori*); the insect spins it round itself in the shape of a hollow ball, called a "cocoon," and remains there till it becomes a chrysalis. But the silk cultivator stops the development of the chrysalis by exposing the cocoons to the action of steam or heated air. The cocoons are then thrown into soft water, best into rain water heated nearly to boiling, and agitated briskly; they are next thrown into tepid water, where the operator takes hold of the end of the thread and attaches it to the bobbin of a reeling machine. The first portions, forming the outer part of the cocoon, are collected separately, and termed "waste silk;" the silk from the inner part of the cocoon constitutes the "raw silk."

The silk fibre is without cellular structure, thus totally differing from wool and the vegetable fibres; its colour varies from white to yellow. The chemical nature of silk has first been investigated by Roard (1807), later by Mulder, and recently by E. Cramer (1863). These researches show that silk consists essentially of two substances: the one constituting the fibre itself, is termed "fibroin;" the other is a varnish or gum covering the fibre. This latter dissolves in hot water, whilst the other is not affected by this agent.

According to Mulder, there are in—

	Yellow silk.	White silk.
Substances soluble in water, ...	28·86	28·10
" " alcohol, ...	1·48	1·30
" " ether, ...	0·01	0·05
" " acetic acid, ...	16·30	16 50
Silk substance (fibroin), ...	53·35	54·05
	100·00	100·00

Cramer's analysis of the purified fibroin points to the formula $C_{30}H_{23}N_5O_{12}$; but formulæ of substances of this kind require to be received with great caution.

A characteristic property of the silk is the absorption of moisture to the extent of 30 per cent.; this moisture is not detected by the touch, and its correct determination is of importance to the buyer as also to the seller. There are special establishments on the Continent, mostly under government inspection, for the valuation of raw silk. The limits of this article do not allow the detailed description of the drying and weighing apparatus employed for that purpose.

Silk stuffs intended to be bleached have either already been partly bleached by the scouring operations which the silk has been made to undergo before weaving, or they are in the raw state. In the former case it is sufficient to immerse the goods for some time in running water; they are then boiled for an hour in a bath, consisting of about 2 ounces of soap and 1 to 1¼ lbs. of bran for each piece of 8 to 10 yards long. The acid of the bran uniting with the excess of the alkali in the soap, prevents it from weakening the silk by dissolving it. On being taken from the bath, the goods are rinsed in water heated to 120° Fahr. (48°·8 C.), and then washed well with cold water in the dash-wheel.

In the second case, the goods, after being introduced into bags, are immersed in a boiler filled with water, holding about ½ lb. of soap to every 2¼ lbs. of dry silk. After having heated and kept the whole in ebullition for two or three hours, the stuff is withdrawn from the bath to rinse it in running water. When well scoured it receives a second soap bath similar to the preceding, and is again scoured by the dash-wheel. The scouring being finished, the silk is passed, during ten or fifteen minutes, into a solution holding about half an ounce of crystallized carbonate of soda for each piece of silk; from this the silk is taken, washed carefully, and then passed into water slightly acidified with sulphuric acid, and after remaining here for some little time it is taken out, washed in warm water, and finally in running water.

Silk fabrics thus bleached are pure enough for every kind of printing in which dark or deep colours are used, such as madder, prussian blue, cochineal, amaranth, and violet; and brown colours in general; but when it is desired to print lighter or more delicate colours, the goods should receive a slight sulphuring. In this case, liquid sulphurous acid is greatly preferable to the gas, and far more advantageous, since it may be employed in a very weak state. Care should be taken that the sulphurous acid be cautiously applied in whitening silk, as it always communicates a more or less yellow tinge, and even injures the thread or fabric after the colour has been abstracted by it.

According to Roard, raw silks, white or yellow, may be completely scoured in one hour, with 15 lbs. of water to 1 of the fibre, and a suitable proportion of soap. The soap and silk should be put into the bath half an hour before its ebullition, and the latter should be turned about frequently. Dull silks, in which the varnish has undergone some alteration, never acquire a fine white till they undergo the operation of sulphuring.

It appears that the Chinese use no soap, but a species of bean, wheat flour, common salt, and water. According to De Grubbens, the proportions used for the bath are 5 parts of beans, 5 of salt, 6 of flour, and 25 of water.

Claussen's process for cleaning silk is—

(1.) Boil it in a soap composed of butter and caustic potash or soda, for 2 or 3 hours.

(2.) Steep in a solution of carbonate of soda or ammonia.

(3.) Sour in a weak solution of sulphuric or muriatic acid.

For bleaching silk—

(1.) Steep in carbonate of soda or ammonia.

(2.) Steep in a solution of sulphurous acid in water, or expose it while wet to the fumes of sulphur.

An artificial shade is sometimes communicated to the silk by impregnating the bath with certain colours. These shades are distinguished by the term china white, azure white, silver white, thread white, &c., and are communicated by the addition of annato to the bath for china white, or by the addition of litmus or indigo in various proportions, as one or other of the shades is desired.

There are various other materials from which it is necessary to remove colouring matters. Such is the case with fatty bodies, oils, straw for artistic purposes, raw material for paper, &c. The methods of bleaching these will be found in the respective articles. We give here, however, that relating to straw.

In Tuscany, where straw for artistic purposes is prepared to a large amount, it is selected whilst the wheat is bearded and the grains are in a soft milky state. The corn is sown very thickly, so as to give a short thin straw. As soon as cut, the straw is spread out for three or four days, and as soon as the sap is dried up, it is tied in bundles and stacked for the purpose of expelling the moisture. Another exposure for some time in the meadows to the dew and atmosphere acts upon the colouring matter and promotes the bleaching. Before the decoloration is entirely effected, it is necessary to turn the straw several times, and to moisten it occasionally with water. When thoroughly exposed, the lower joints of the straw are cut off, and the parts chosen for use are acted upon by steam, which dissolves most of the remaining colouring matter, and then it is submitted to the vapour of sulphur to decompose the residue.

In this country the straw is prepared by acting upon the ordinary materials; first, with a boiling solution of caustic soda, by which a considerable portion of the organic matter and natural varnish is disintegrated; after this it is washed well to remove all the material which the alkali dissolves, and then exposed to the action of the vapour of sulphur, or to bleaching powder, in confined vessels. Care should be taken that the sulphuring does not produce any charring of the straw by its too rapid combustion, for this cannot be remedied when once it has taken effect. Three or four hours' exposure to sulphurous acid, and about the same time to the solution of bleaching powder, is sufficient to remove the stains remaining.

Kurrer states that the straw may be economically whitened by being steeped repeatedly in boiling water and very weak alkali, and after the whole of the soluble matters are in this way removed, treating alternately with very dilute solutions of oxychloride of calcium and sulphurous acid vapour till the decoloration has been effected. This method, though tedious, is said to be very effectual for divesting the straw of its natural varnish, which renders it brittle.

BONE.—*Os*, French; *Knochen*, German; *Os*, Latin. —The various parts of the skeleton, or the solid framework supporting and protecting the softer portions of the body of animals of the superior orders, are termed bones. They are invested with a thin membrane called the *periosteum*, which is traversed by the nerves and bloodvessels, and has beneath it a still thinner membrane. These together compose a thick tissue which is convertible into jelly by boiling with water, affording glue, &c.

Bones are not equally solid throughout, but present to view on the surface an osseous mass of a more compact nature, while the interior appears as a cavity divided into minute cellules by bony partitions. The cartilaginous portion is formed before the deposition of the earthy substance occurs, and the ossification always proceeds from certain fixed points. Bony tissue consists of bone-cartilage, or *ossein*, and tribasic phosphate of calcium, Ca_3PO_4, together with phosphate of magnesium, Mg_3PO_4, carbonate of calcium, and fluoride of calcium.

The organic part of the bones may be obtained in a separate state by immersing them in dilute hydrochloric acid. The lime salts are dissolved by the acid, and a kind of skeleton remains in the form of a cartilaginous substance, transparent, flexible, and elastic, exactly retaining the form of the bones; this, when dried, resembles horn. By boiling in water it is totally converted into gelatin, with the exception of a few fibres, derived from the fine blood-vessels, which are insoluble, and may be separated by filtration.

The chief difference between bone cartilage and gelatin is that the latter dissolves very rapidly in hot water, whilst the bone-cartilage is insoluble until it has been by long boiling converted into gelatin. The chemical constitution of the two are almost identical.

	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	
Isinglass,.......	50·76	6·64	18·32	24·69	MULDER.
Bone-cartilage,..	50·13	7·07	18·45	24·35	VON BIBRA.

Bone ash—the earthy salts of bones—is best obtained by calcining the bones; but there are substances then present which did not antecedently exist in them—as, for example, sulphate of soda, formed from sulphur in the cartilage—there are also some alkaline carbonates derived from the same source. The carbonate of lime of the bone loses most of its acid at a white heat.

BONE GLUE—*Patent Glue.*—The manufacture of glue from bones is thus described by WAGNER.

Boiling out the Grease.—The bones are put into water and boiled in a cauldron, the fat floating to the surface. Frequently, in order to save fuel, the bones are put into an iron-wire basket, which is removed after the boiling has continued for some time, the bones thrown out and fresh ones put in, the boiling being continued until a thick gelatinous liquor is obtained. The fat or grease is removed from the surface by means of ladles. The gelatinous mass obtained by this process is either used as a manure or given to cattle. In some works bones have been exhausted with bisulphide of carbon for the purpose of extracting the grease.

Treating the Bones with Hydrochloric Acid.—The bones having been drained are placed in baskets, and with these are immersed in tanks to more than half their height, the tanks being filled with hydrochloric acid at 7° B.(= 1·05 spec. grav. = 10·6 per cent. of hydrochloric acid). Ten kilogrammes of bones (22 lbs.) require 40 litres (8·8 gallons) of acid. The bones are kept in this liquor until they become quite soft and transparent. They are next drained, and then with the baskets immersed in a stream or brook, with a good supply of running water to wash out the greater portion of the acid, which is fully neutralized by placing the bones in lime water, again followed by washing with fresh water. The bones are then ready for boiling.

Dr. GERLAND has suggested the use of sulphurous acid instead of hydrochloric acid.

Conversion of the Bone Cartilage into Glue.—The cartilaginous substance having been either partly or completely dried, is put into a cylindrical vessel containing a perforated false bottom, and between that and the real bottom a tube. To the top of the vessel a lid is fitted, provided with an opening for a steam-pipe leading from a small boiler. Shortly after the admission of the high-pressure steam a concentrated glue solution begins to run off from the pipe at the bottom of the cylinder; this solution is usually so concentrated as to admit of being at once run into moulds, and when solidified the jelly is cut into cakes of the size and shape met with in the trade.

The moulds into which the glue solution is poured (through a strainer made of metal gauze) are of wood, and generally a little wider at the top than at the bottom, so as to admit of an easy removal of the solid material. At the bottom of the moulds a series of grooves are cut at such a distance from each other as agrees with the size of the intended glue cake. Before the liquid is poured into the moulds they are thoroughly washed, and either allowed to remain damp, or if dried, are oiled so as to prevent the solidifying gelatin from adhering to the wood. Recently moulds made of zinc and sheet iron have been introduced.

The moulds are filled with lukewarm glue solution, and when the glue is sufficiently hard, it is gently loosened from the sides with a sharp tool, and the mould having been turned over on a wooden or a stone table, previously damped, is lifted off the block of gelatin, which is next cut into cakes or slabs. The cutting tool is simply a piano-wire, or more frequently a series of these stretched in a frame, at a sufficient distance from each other to make the cakes of the desired thickness, the frame being placed on small wheels so as to be easily moved.

Drying.—This operation is performed by placing the gelatin cakes on nets made of twine, stretched in frames, and exposed in a dry airy place to the action of the sun. The drying is the most difficult operation of the glue-making process, because the temperature of the air and its hygrometric condition exert a great influence on the product, especially during the first few days. The glue will not bear a temperature above 68° Fahr. (20° C.), because at a higher temperature it becomes again fluid, and as a matter of course flows through the meshes of the net, and adheres to the twine so strongly as to require the nets to be put into hot water for the removal of the mass. Too dry air causes an irregularity in the drying of the glue, and as a consequence the cakes become bent and cracked; while frost causes disintegration so as to necessitate remelting of the glue; hence it follows that drying in the open air can only be effected in the spring and autumn.

The glue boilers have tried to dry glue by artificial heat, but this plan has not been much adopted, owing to the fact that a slight excess of heat causes a re-melting of the gelatine, and this the more readily if ventilation is at all neglected.

Drying rooms, as recently constructed, are large sized sheds, fitted with the required frame-work for receiving the gelatine cakes, and heated by steam pipes placed on the floor near the latter. The walls are provided with openings which can be closed by means of valves, while there are ventilators in the roof arranged to obtain a proper circulation of air. As the glue placed nearest to the floor becomes soonest dry, it is, with the frames upon which it is placed, removed after eighteen to twenty-four hours to a higher part of the drying room, which is not heated at all if the outer air has a temperature of 60° to 68° Fahr. (15°·5 to 20° C.). The drying shed, or room, is by preference built so as to face the north.

When the glue has been thus dried as much as possible, it is generally quickly dried in a stove in order to impart hardness. It is next polished by being immersed in hot water, then cleaned with a brush, and again dried.

BONE BLACK—ANIMAL CHARCOAL.—*Noir d'os*, French; *Knochenschwartz*, German.

PROPERTIES.—Bone black possesses the property of abstracting many solid substances from solution, and of completely absorbing the colour of very many vegetable and animal solutions, and of rendering quite limpid and colourless the water charged with it. Vegetable charcoal shares this property with it in a certain degree, but does not possess the same energy. Animal charcoal differs very materially in appearance and in physical and chemical properties from vegetable charcoal. The former in a newly manufactured state obstinately refuses to part with the whole of its nitrogen, and this can only be got rid of by repeated washings with hot water and reburnings.

The first observations on this subject were made by LÖWITZ at the close of the last century. He observed with care the decolouring properties of vegetable charcoal, and endeavoured to make some applications of it. From 1800 to 1811 it was extensively used for depriving crude syrups of colour; but at the latter date M. FIGUIER, an apothecary of Montpellier, showed that the same effect was produced by animal charcoal, not only in a better manner, but also more speedily and certainly. The discovery was promptly applied to the refining of sugar, and now forms one of the most essential processes of that art.

In using animal charcoal for depriving a liquid of its colour, the operation is more successful when the latter is slightly acid or neutral, than when it is alkaline.

The action of animal charcoal on coloured liquids is usually accelerated by heat. In most cases the liquor to be deprived of colour is brought to a state of ebullition, the charcoal is thrown in, the mixture agitated for some moments, and then filtered.

Animal charcoal is almost always prepared from the bones of the ox and the sheep, horse bones are seldom used as they produce an inferior charcoal. It contains, therefore, the salts of lime, which enter into the composition of these bones; and consists of about 10 per cent. of nitrogenized charcoal, 2 of carbide or silicide of iron, and 88 of phosphate or carbonate of lime, mixed with a little sulphide of calcium, or of iron.

The animal charcoal of commerce is subject to very great variations in quality, due to various conditions of the raw material and bad manufacture. When either over or under calcined, it is less energetic; in the former case, because it is less porous; in the latter, because the animal matter, not being quite consumed, makes a kind of varnish in the charcoal which prevents its acting The best of all is that which has been calcined to the exact point of destroying the animal matter, but no further.

The state of porosity of the charcoal is important. Thus the charcoal obtained by calcining a mixture of potassa and animal matter in the manufacture of prussian blue, and which remains after the lixiviation of the residues, possesses the decolouring property to a degree which ordinary bone-charcoal never attains. This charcoal is pure; the decolouring power of this charcoal is ten times more energetic than that of crude bone black.

The following table of the decolouring power of different varieties of charcoal is by BUSSY:—

Species of charcoal.	Weight.	Indigo test consumed	Molasses test consumed.	Blanching by indigo.	Power by molasses.
	gramme.	litres.			
Blood calcined with potassa,	1	1·60	0·18	50	20
Blood calcined with chalk,	1	0·57	0·10	18	11
Blood calcined with phosphate of lime,	1	0·38	0·09	12	10
Gelatin calcined with potassa,	1	1·15	0·14	36	15·5
Albumen calcined with potassa,	1	1·08	0·14	34	15·5
Starch calcined with potassa,	1	0·34	0·08	10·6	8·8
Charcoal from acetate of potassa,	1	0·18	0·04	5·6	4·4
Charcoal from carbonate of soda by phosphorus,	1	0·38	0·08	12	8·8
Calcined lamp-black,	1	0·128	0·03	4	3·3
Lamp-black calcined with potassa,	1	0·55	0·09	15·2	10·6
Bone black treated with hydrochloric acid and potassa,	1	1·45	0·18	45	20
Bone black treated with hydrochloric acid,	1	0·06	0·015	1·87	1·6
Oil calcined with phosphate of lime,	1	0·064	0·017	2	1·9
Crude bone black,	1	0·032	0·009	1	1

In fact, the charcoal proceeding from pure organic matter has little decolouring power. That which is mixed, on the contrary, with abundance of earthy matter, decolours tolerab'y well, and that which has been formed in the midst of fusible saline substances still better. Charcoal of the second and third classes is always of a dull colour, which implies that it exists in a very minute state of division. Bussy and Payen have shown that they took from some, and imparted to others, the decolouring property, according as they rendered them lustrous or dull, by suitable modifications in the process of carbonization.

The first and most striking fact seen on referring to the table is, that the relative decolouring powers as measured by indigo or molasses are far from being identical. The author of the table remarks on this subject, that the more charcoal a substance requires for its decolouration, the more does the decolouring power of the perfect charcoal tend to diminish, as compared with the ordinary bone-charcoal taken for the unit measure of this energy, in all cases.

A result not less evident is, that the blanching power is inherent in the pure carbon, since that which is obtained from the decomposition of carbonate of soda possesses it in a high degree. Moreover, although the facts relative to the decolouring power of animal charcoal have been here brought together, this property must be considered as common to every kind of charcoal, provided it exist in a minute state of division.

In recapitulation, it will be seen from what has just been stated, firstly, that the decolouring property is due to the charcoal; secondly, that it is modified, nevertheless, by the presence of earthy salts; thirdly, that the charcoal acts by combining with the colouring matter; fourthly, that this combination is effected according to the fine division of the particles of the charcoal; fifthly, that this state may be communicated to it by a suitable mixture of mineral matters, particularly of potassa, during carbonization, provided they are supplied in sufficient quantity to prevent the charcoal from agglomerating.

It was formerly the general opinion that the action of animal charcoal was only exerted upon bodies of organic origin, particularly colouring principles, bitter and aromatic substances, as turmeric, litmus, indigo, sugar, syrups, &c.

Graham has, however, found that inorganic matters were equally influenced, and it has been proved that charcoal abstracts the lime from lime-water, and completely absorbs the metallic oxides, particulary those of lead, as also ammonia and potassa, from their aqueous solutions. According to experiments conducted by Chevallier, neutral acetate and nitrate of lead are entirely taken up by bone charcoal, whether it is in a washed or unwashed state. The former is more readily absorbed than the latter. The absorption requires—with from one to ten parts of charcoal to one of the salt—from one or two to six days at the ordinary temperature, but at a boiling heat from two to five minutes only.

Graham, by bone charcoal, even separated the iodine from iodide of potassium. The investigation of Weppen appears to prove that the action of the charcoal extends to all metallic salts; with the following no doubt remains of this being the case, viz.: the sulphates of copper, zinc, chromium, and protoxide of iron, nitrates of nickel, silver, cobalt, sub-oxide, and oxide of mercury, acetate of lead, tartrate of antimony, and potassa, protochloride of tin, protochloride of mercury, and acetate of the sesquioxide of iron. In the separation of these salts by charcoal, one of three cases may occur: the salt is absorbed unchanged: or a basic compound is precipitated upon the charcoal: or the oxide in the salt is reduced to the metallic state. Some metallic acids, as antimonic and tungstic, are thrown down from their potassium or ammonium salts, although no effect is produced on arsenite or arseniate of sodium. The salts of the alkaline metals are little affected. Free acids either hinder or entirely prevent the precipitation of the metallic oxides.

Preparation.—The first step in the preparation of animal charcoal is to take what are technically termed "raw bones," which possess a certain amount of grease, this together with some gelatine is removed by boiling. The grease is used in the manufacture of candles and soap; the gelatine, when concentrated, is employed in sizing cloths, yarns, &c. The bones after being boiled are subjected to the influence of a red heat for some hours.

Fig. 1.

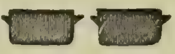


Fig. 2.

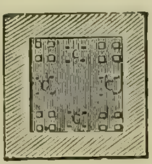


Fig. 3.

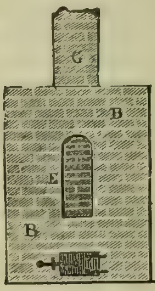
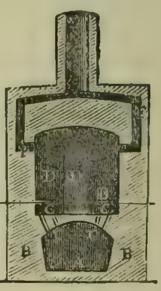


Fig. 4.



The calcination of bones to produce animal charcoal is conducted in different ways; by one method the bones are calcined in small pots closely packed up in a kiln. On this plan the bones, broken into small fragments, are placed in small cast-iron vessels of the form shown in Fig. 1, about three-eighths of an inch in thickness, two of which, after filling, are dexterously placed with their mouths in contact, and then luted together with loam. The lip of the upper is made to fit inside that of the lower one. These double vessels, a pair of which contain about 50 lbs. of bones, are arranged in parallel rows, and also upon each other, in an oven, till it is filled. This oven or kiln may be either oblong or upright. The latter is represented by Figs. 2, 3, and 4. A is the fireplace, or grate for the fuel; C C are apertures in the dome of the furnace for the admission of flame; the divisions of these orifices are shown in Fig. 2; B is the wall of brickwork; D is the space where the pots are placed; E is the door by which the workmen carry in the vessels, and which, before the carbonization commences, is built up with firebricks and plastered over with loam; F F are flues for carrying off the disengaged gases into the chimney, G.

Fig. 5 is a longitudinal section and Fig. 6 a ground plan of a horizontal kiln for calcining bones. A is the fire-chamber, on a level with the sole of the oven; it is separated from the calcining hearth, C, by a pillar, B. In this pillar or wall several rows of holes, D, are left at different elevations; E is the entrance door; F F are the outlet vents for the vapour, smoke, and gases into the chimney, G; a sliding damper plate, for regulating the admission of air into the fire in the space, A, is denoted by H.

The offensive emanations are, by this arrangement, partly consumed and partly carried off with the smoke. For the complete destruction of the smell the vapours, &c., should pass through a small furnace, or be otherwise submitted to combustion.

In both the kilns represented the interior walls are built of firebricks. In the oblong one the heat is greatest near the vaulted roof; in the upright one, near the sole; the pots containing the larger lumps of bones should be placed accordingly. The former oven is generally constructed to contain from 100 to 150, and the latter about 70 pots; the dimensions may, however, be varied at pleasure.

Fig. 5.

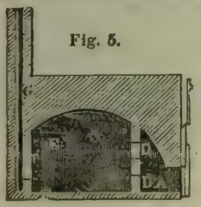
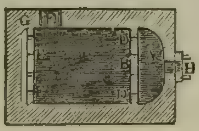


Fig. 6.



After the pots have been properly packed into the oven, and the entrance door is closed, the fire is at first kept low, but is afterwards raised and a brisk heat maintained for eight or ten hours. The draught is then moderated by the door of the ash-pit, and the damper being nearly closed, a steady ignition is kept up for an additional six or eight hours without fresh firing, after which time the doors are opened to cool the furnace. After this has been effected the brickwork which closed the entrance is taken down and the kiln is emptied, but is immediately filled again with a fresh set of vessels previously prepared. The pots just withdrawn are, after a short period, opened, and the contents put into the magazine.

When the preparation of bone black is connected with that of ammoniacal salts, the carbonization is performed in cylinders of cast iron, terminated at one extremity by a pipe of 3 inches diameter, which conducts the evolved gases into a long series of refrigerating apparatus. The other end is opened or closed at will by means of a movable disc of the same metal. These cylinders are placed horizontally in a furnace. They are filled with crushed bones, previously deprived of their fatty matter, and the disc being closed and luted, the temperature is raised to a red heat and maintained at that point for thirty-six hours; at the end of which time the lid is opened, the residue withdrawn, and inclosed in metal receivers or boxes, to be extinguished while the cylinders are recharged.

Bone black thus prepared requires reducing to a finer state of division. For this purpose it is first crushed to a coarse powder, and the process is concluded by passing it between stones, similar to those used for grinding corn, but it may be pulverized between steel cylinders, and in many other ways. It is generally damped during grinding to lay the dust which would otherwise rise.

The ammoniacal liquid produced in distillation of the bones is saturated with sulphuric acid, and evaporated to form sulphate of ammonia.

If it is not desirable to collect the other products of the distillation of the bones, the pipe which allows their escape may be immediately carried under the firegrate, where combustion will ensue, thus not only avoiding their disagreeable odour, but also economizing fuel.

Bone black is sometimes employed as a pigment; and as in this case it requires to be more thoroughly divided, it is made into a liquid paste with water, which is put into *a colour-mill*, and ground for the necessary time; the resulting mass is then put into earthen moulds, and left to dry.

Bone-black forms the base of blacking; it is also used by some sugar refiners in the early stages of refining. The animal charcoal dust unsuitable for sugar refining purposes is converted by sulphuric acid into superphosphate of lime. Animal charcoal is the only form of charcoal now used by British refiners, and the quantity of bones annually used in its manufacture in this country is over 25,000 tons. The largest manufacturers in the world are G. Lockyer & Sons of London and Bristol; the oldest houses in the trade are those of G. Torr, London, and Eden, Jones, & Co. of Bristol; the latter is now merged into that of G. Lockyer & Sons.

Ivory-black is obtained by analogous processes. It forms a beautiful velvety black, which is used in making the best printing inks.

Revivification.—On the Continent, the renovation of the charcoal, with some slight modifications in the methods of carrying it out, consists in submitting it to fermentation; washing (in some cases with hydrochloric acid, and afterwards with water; in others, with water only); drying; and finally heating to redness.

During this second burning the temperature is much lower than that originally required; consequently, the operation is effected without pots, and the danger of burning the charcoal to ash is proportionally diminished. In France the process is conducted in reverberatory furnaces, having a flat-arched roof, and the doors made very close. In Magdeburg, narrow cylinders, fitted at the top with a lid, and below with a sliding door, are used, several of the retorts being at the same time placed upright in a reverberatory furnace.

The fermentation of the charcoal previous to burning is advantageous, as the greater portion of the absorbed organic matters is decomposed and evolved as gas, leaving only a small quantity in the pores to be charred. On the other hand, however, it converts any lime which may have been taken up into carbonate, and renders its removal more difficult.

One of the best methods is that proposed by Schatten, and carried out at Magdeburg. As the charcoal leaves the filters, and before the lime has had opportunity for absorbing carbonic acid, it is completely saturated with dilute hydrochloric acid, which immediately acts very energetically, and causes evolution of much heat. The charcoal is then placed in large reservoirs, and water, mixed with about one-half per cent. of hydrochloric acid, poured upon it. This treatment occasions a lively fermentation, which extends over about eight days, when the water is removed, and another quantity of fresh supplied. After this has been repeated several times, the charcoal is treated with water, again containing acid, in smaller vessels, until the lime is completely saturated, when it is again washed, and then heated to redness. Any excess of acid must be carefully avoided, as it would attack the phosphate of lime, soften the charcoal, and render it useless. The upper layers of bone-black in the filters which first come into contact with the saccharine juice, hold six times as much lime as those below.

Fig. 7.

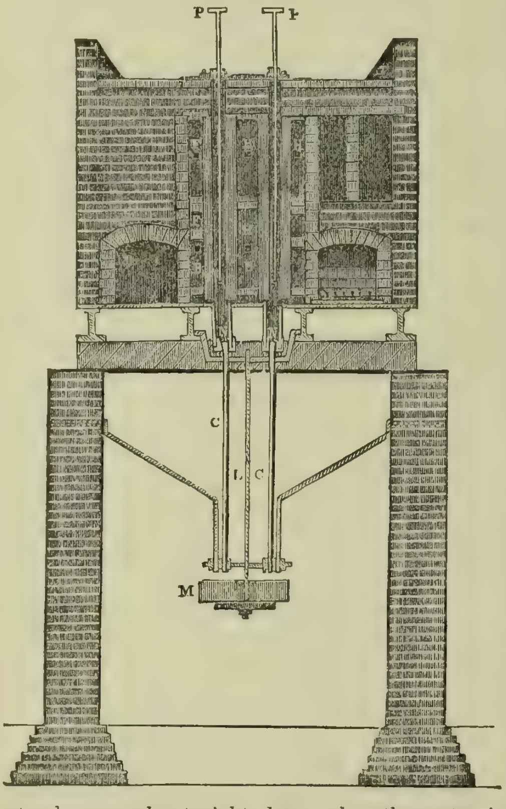


Fig 7 is a sketch of Parker's charcoal re-burner, patented some years ago.

Narrow spaces constructed of firebrick, the bottoms of which are indicated in the engraving at N, are surrounded by the flames from a fire passing up the flues, B, F, and H, which retain them at a low red heat. These narrow upright brick retorts are connected below, so as to be air-tight, with the still narrower sheet-iron receivers or coolers, C C, into which a certain quantity of the re-burnt charcoal can be allowed to fall at short intervals, and cool without access of air. It is ultimately removed underneath, passing through the measurer, M. The re-burners are open at the top, where the charcoal is admitted and piled up in a heap above the aperture, so that, as one portion is removed below, its place is immediately occupied by a quantity falling down from above. P P are tubes through which the temperature in the interior of the charcoal can be observed, and which also serve as an exit for the gases evolved in the lower part of the re-burners.

Figs. 8, 9, and 10 represent the apparatus of Pontifex and Wood—the first being a plan, the second a longitudinal, and the third a transverse section.

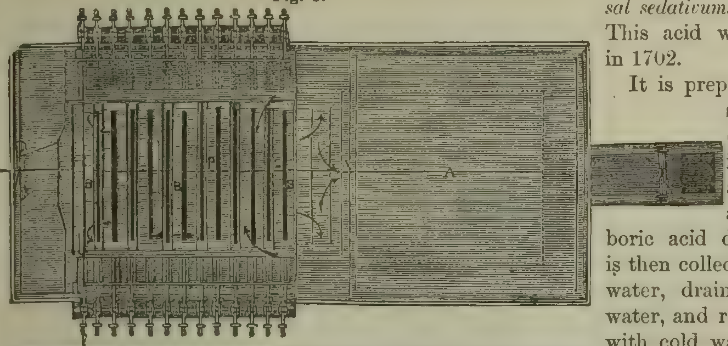
The charcoal that has been used in the filters, after having been washed in a cistern, is taken out and laid aside to allow the water to drain from it; it should then be removed to the re-burner, and placed on the wrought-iron plate, A, which forms the back part of the top; the fire having been lighted, the plate will become hot, and thoroughly dry the charcoal before the retorts, B B B, B B B, are heated. When it has become perfectly free from moisture, it should be raked forward into the retorts, filling them up, and heaping the charcoal over them to the height of 6 inches or more. After the retorts are thus charged, a red heat is applied for fifteen or twenty minutes, after which the operation is finished.

The slides, *a a*, in the boxes, C C—Fig. 10—are then opened, which allows the charcoal contained in the pipes, D, and a portion of that in the retorts, to run into C C; the slides are subsequently closed, the charcoal descends, and the hollows produced in the heap over the retorts are supplied from the charcoal on the plate, A. The slides, E E, at the bottom of the boxes are now opened, and the charcoal having become tolerably cool is run into trucks or boxes placed below C C, when, after a little water has been thrown on it to reduce the temperature still further, it may be stowed away, ready for use. The first charge is never properly burned, a portion having been left in the pipes, D D, which are below the heat of the fire; this must, therefore, be again thrown on the top of the retorts. After the apparatus is once at work, a charge may be drawn every fifteen or twenty minutes, according to the temperature, which may be regulated by the damper, F.

The fire in this arrangement should never be put out, as the cooling of the retorts soon destroys them. They may be worked at any velocity, by allowing a greater or less draught, but the charcoal must never be permitted to become red-hot above the tops of the retorts, where it is in contact with the air. If the charcoal is properly heaped up over the retorts, and the charge drawn regularly, the apparatus works admirably.

The receptacle, C, into which the charcoal is let down when it is sufficiently burnt, is divided into as many compartments as there are retorts, each holding half the quantity burnt in one of them, the corresponding receptacles on the other side of the apparatus having the remainder. The valves, *a a*, are flat plates of cast iron working in grooves, and are intended to open or close the communication between the retorts and the receptacles. They are worked by the handles abutting on each side of the plan.

Fig. 8.



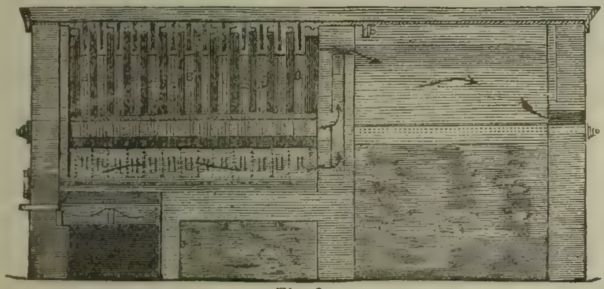
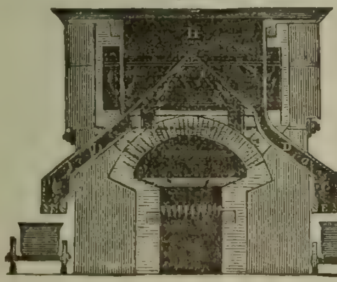


Fig. 9.

In the longitudinal section of the re-burner, a section is shown of the whole of the retorts cut across in the middle, on the line of the union of the two legs; and consequently it shows the end-sides of the retorts slanting towards these legs, or "breechings," as they are termed.

Fig. 10.



The transverse section shows the retorts cut across the middle at right angles to the longitudinal section.

The direction of the flues is shown by the arrows on the drawings. Each retort revivifies 50 lbs. of charcoal every fifteen or twenty minutes, and, conquently, the burner revivifies about 9½ cwts., at least, of spent charcoal per hour.

Some substitutes have been proposed for bone charcoal; none of them, however, are of equal power. The best hitherto known is that obtained from bituminous shale. This mineral is constituted, like bone, of an earthy and an organic constituent, and yields a similar charcoal. Another imperfect substitute is obtained by charring molasses.

BORACIC ACID.—BORIC ACID.—*Acide boracique, acide borique*, French; *acidum boracis*, Latin; *sal sedativum, Hombergii, sal narcoticum vitrioli.* This acid was first obtained by HOMBERG in 1702.

It is prepared in the pure state by dissolving 40 parts of sodium biborate (borax) ($2NaBO_2,B_2O_3, 10H_2O$) in 100 parts of boiling water, and adding 25 parts of hydrochloric acid to the hot solution. The boric acid deposits as the liquor cools; it is then collected on a filter, washed with cold water, drained, redissolved in a little hot water, and recrystallized, the crystals washed with cold water and pressed between folds of bibulous paper. The mother liquor and the washings on evaporation afford a further quantity of the acid. The boric acid, when dry, still retains a trace of free hydrochloric acid, which may be driven off with a part of the water of crystallization by heating to a temperature of about 234° Fahr. (111°·1 C.). The usual method consists in decomposing borax with sulphuric acid; but the boracic acid thus obtained is always contaminated with a certain portion of the sulphuric acid, which is dissipated only with great difficulty.

The crystallized hydrate of boric oxide, *i.e.*, boric acid, is soluble in 25·7 parts of water at 64°·4 Fahr. (18° C.), in 14·9 parts at 77° Fahr. (25° C.), in 10°·7 parts at 122° Fahr. (50° C.), in 4·7 parts at 167° Fahr. (75° C.), and in 2·97 parts at 212° Fahr. (100° C.). Its solubility is much increased by the presence of tartaric acid or tartrates. From the boiling solution it deposits as it cools in pearly six-sided scales, having the specific gravity 1·48. Boric acid dissolves in alcohol, to the flame of which it communicates a beautiful green colour. It also dissolves in several of the mineral acids, especially sulphuric. It has little taste, and colours litmus deep red in the cold, but scarlet when hot; it renders turmeric brown, like an alkali. The glacial acid, when exposed to the atmosphere, absorbs water, intumesces, and becomes opaque; it is readily fusible, and forms combinations with many of the metallic oxides having the same property. At a white heat boric acid slowly sublimes when exposed to the air. When perfectly pure, and slowly deposited from its aqueous solution, it forms small, white, translucent, prismatic crystals.

Heated to 212° Fahr. (100° C.) boric acid parts with 21·8 per cent. of its water; heated for some time at 320° Fahr. (160° C.) it is deprived of more water and becomes $H_2B_4O_7$. At a red heat the whole of the water is volatilized, leaving boric oxide (B_2O_3).

The green colour communicated to the flame of alcohol is so peculiar that it is used as an indication of the presence of this acid. If a salt, free from copper, for example, be suspected to contain boracic acid, a little sulphuric acid is added, and the mixture dried by a gentle heat; this will separate the boracic acid and dispel any chlorine or hydrochloric acid that may be present, which also gives a greenish-blue flame. On adding alcohol to the dry mass and igniting; if the smallest quantity of this acid be present the green tint will sooner or later appear, especially if the mixture be stirred rapidly with a glass rod.

When boracic acid is perfectly dry it is fixed; but during the ebullition of its aqueous solution it is carried off by the vapour in large quantity. On being distilled with alcohol a still larger portion of the acid is carried off in the spirituous vapour than is the case with the steam.

By the action of boric acid on metallic oxides or their salts, borates are formed. Boric acid is, however, so feeble in its affinities at ordinary temperatures that its salts are completely decomposed by nearly all acids, including carbonic acid and sulphuric acid, and are in dilute solution even split up by water.

When concentrated, on the other hand, boric acid decomposes carbonates and soluble sulphides, and as before remarked, its anhydride at fusing temperatures sets free all volatile acids from their metallic combinations.

The preparation of boric acid, on the large scale, has been well described by Payen, *Précis de Chimie Industrielle.* The works in Tuscany are situated on a gently sloping ground, constantly disintegrated by currents of gas and of vapours, which project liquid columns in the middle of small basins of water, and afterwards rise into the air in whitish clouds. At the bottom of these hills are situated the manufactories, at a short distance from each other. They are named Larderello, Monte-Cerboli, San Frederigo, Castel-Nuovo, Sasso, Monte-Rotundo, Lustignano, Serazzano, and Lago. In these establishments, although an enormous mechanical force is incessantly manifested, and an evaporation effected exceeding 7875 tons of water annually, and producing about 738 tons of crystallized acid; neither machines, nor crude substances, nor combustibles, are perceptible. The *soffioni*—numerous jets of vapour—do the whole of the work; it is merely requisite to give their powerful blast a proper direction, to obtain both the crude solution and the heat required for its concentration.

The lagoons of Tuscany are spread over a surface of 30 miles. As they are approached, the earth seems to pour out boiling water as if from volcanoes of various sizes. The soil varies, but is principally chalk and sand. The heat in the immediate vicinity is intolerable, and the vapour impregnates the atmosphere with a strong and somewhat sulphurous smell. The whole scene is one of terrible violence and confusion—the noisy outbreak of the boiling stream—the rugged and agitated surface—the volumes of steam—the impregnated atmosphere—the rush of waters among bleak and solitary mountains.

The ground, which burns and shakes beneath the feet, is covered with beautiful crystallizations of sulphur, &c. Formerly the place was regarded by the rustics as the entrance of hell, a superstition derived no doubt from ancient times, for the principal of the lagoons and the neighbouring volcano still bear the name of Monte Cerboli—*Mons Cerberi.* The peasantry never pass the spot without counting their beads.

The lagoons have been brought into their present profitable action within a very few years. Scattered over an extensive district, they have become the property of Count Larderel, to whose energy and intelligent skill the great increase in the production of boracic acid of late years is due.

Many difficulties have impeded this manufacture; but Count Larderel has succeeded in overcoming the most serious by substituting, instead of the expensive wood fuel, a most happy application of the superabundant vapour which everywhere escapes from the soil, and by which a saving of nearly £500,000 has been effected. Payen, in his researches into the nature of the gases, and of the substances which they carry with them into the lagoons (small muddy lakes), found the non-condensed gases to consist of—

	Centesimally.
Carbonic acid,	57·30
Nitrogen,	34·81
Oxygen,	6·57
Sulphide of hydrogen,	1·32
	100·00

The condensable products, and the substances conveyed by the currents of vapour, vary: generally they comprise water, clay, sulphates of lime, of ammonia, of alumina, and of iron, hydrochloric acid, organic substances, and lastly, little or no boracic acid; they deposit sulphur in all the narrow fissures and pores which they traverse. The temperature of these vapours was found to vary from 206° to 212° Fahr. (96°·6° to 100° C.).

It has been found impossible to obtain this acid by condensing the vapours of the soffioni, even in very large and long tubes; to obtain it, it is requisite that their apertures should be directly covered by the liquid of the basins. It is frequently observed that a portion of the water absorbed, when these lagoons are filled, is subsequently thrown out with the vapour. And though the cause of the currents of gas, and of the elevation of the temperature, appears to have remained constant for many years, the production, or at least the arrival of the boracic acid at the surface of the soil, seems to depend on the introduction of water into the fissures.

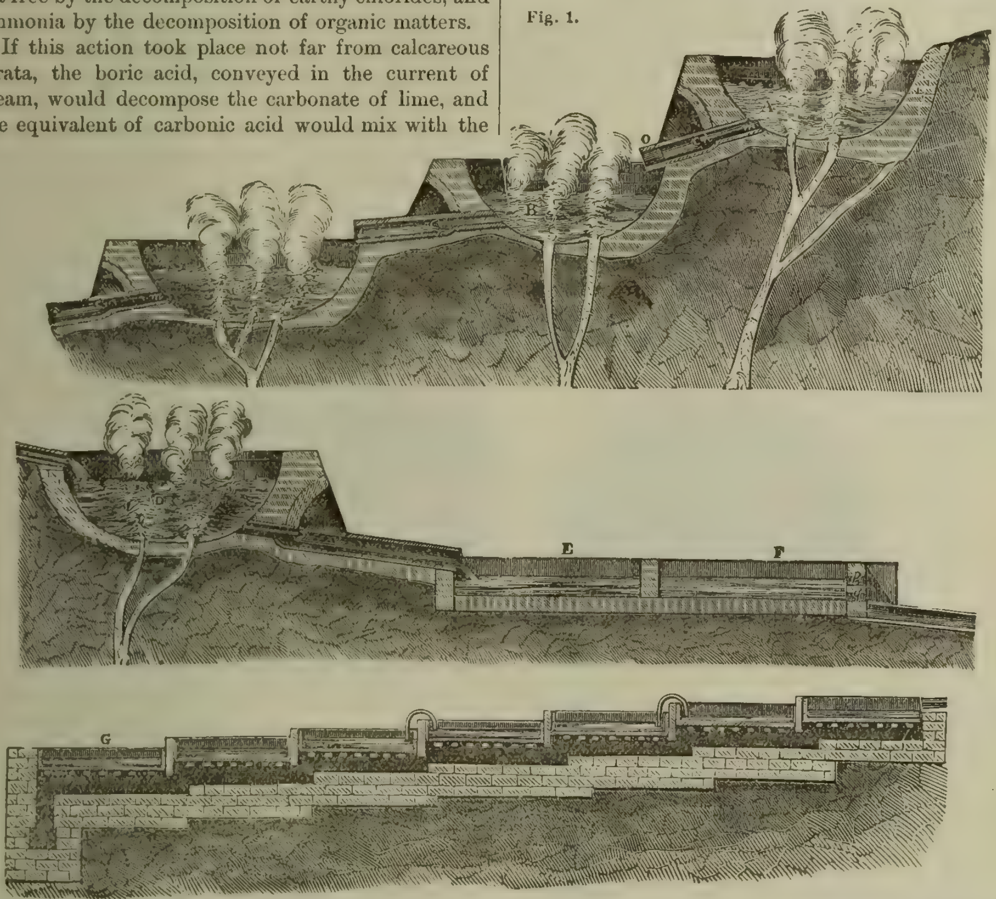
Suppose the water of the sea, percolating through some fissure to a great depth, had its temperature raised to a high degree, and that it found in the soffioni an issue for the steam produced, the vapour, mixed with the projected water in passing over the deposits of boric acid, would carry this with it, and by the reaction of the organic matter contained in it on the sulphates, would produce sulphides, from which boric acid would expel sulphide of hydrogen.

DUMAS has suggested that a deposit of sulphide of boron, situated at a great depth, is percolated by sea-water; a considerable action takes place, from which results boric acid and sulphuretted hydrogen at a high temperature, these products being evolved together with the steam. Hydrochloric acid is also set free by the decomposition of earthy chlorides, and ammonia by the decomposition of organic matters.

If this action took place not far from calcareous strata, the boric acid, conveyed in the current of steam, would decompose the carbonate of lime, and the equivalent of carbonic acid would mix with the other gases. At a certain distance the sublimed boric acid might form deposits, and, according as the water of the lagoons descended to this point or not, the current would again carry up with it boracic acid, or pass without volatilizing it. The air furnished by the sea-water would enter the fissures, and in the presence of sulphuretted hydrogen would determine the formation of sulphuric acid. This, in its turn, would produce sulphates of calcium, of ammonium, of aluminium, and of iron, taking the lime from the calcareous mass, the ammonia from the vapours, and the alumina and iron from the clay.

These different salts are formed, or dissolve in the waters near the surface of the soil, and explain its disintegration. The appearance of sulphur, and the presence of a little oxygen, which accompany the various substances contained in the soffioni and in the troubled waters of the lagoons, results from the accidental introduction of air.

Fig. 1.



The methods adopted in the nine manufactories are, with some slight modifications, identical: they consist in the construction of rude circular basins (Fig. 1) around each of the centres of irruption, where two or more of the largest fissures terminate; and further, in conveying into the highest of these basins or lagoons, A, the water of some neighbouring spring. After remaining in the basins for twenty-four hours, during which time the water has been constantly agitated by the subterraneous jets, the plug, O, is opened, and the liquid passes by a small canal, *m n*, into the lower lagoon, B, where it is confined for the same length of time, and becomes charged with more boric acid. The solution is successively passed into the lagoons, C, D, the liquid, as it is drawn off from an inferior basin, being constantly replaced by that contained in the one above.

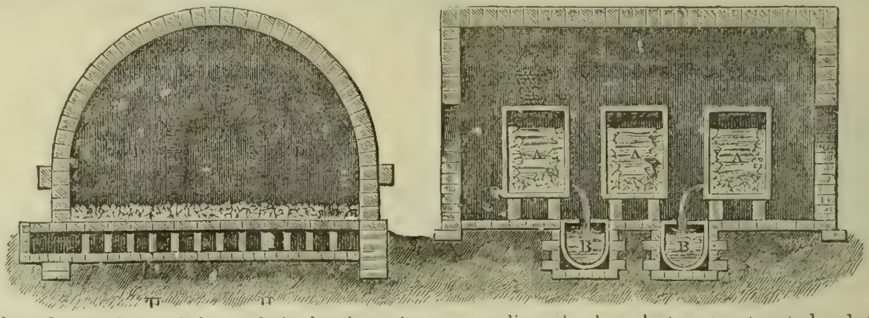
All experiments made with a view of obtaining the boric acid directly by condensing the vapours in towers or chambers, have been fruitless.

When the solution has arrived at the last lagoon, D, and is sufficiently saturated, it is transferred into a reservoir, or cistern, E, 20 feet square and a little more than 2 feet deep, where the greater portion of the sediment is deposited. The supernatant liquid is decanted either into a second reservoir, F, or into two batteries, each of seven leaden evaporating pans, G G, 10 feet in breadth and 14 inches in depth, supported by strong wooden rafters above the masonry, on an inclined plane, which allows the vapour from some soffioni inclosed in pipes, and which enters at H, to ascend freely beneath the pans, which are arranged on different levels, to the upper portion, where the excess is given off outside the factory. The solution of the boracic acid in the reservoirs has usually a very low specific gravity. The four first pans of each double range are filled with the clear liquid by removing the upper plug, P. At the end of twenty-four hours the solution, diminished to about one-half of its volume, is transferred by means of siphons into the next pans of each range, and is replaced by the product of a fresh decantation from the reservoir. Twenty-four hours later, the liquor, again reduced to half its volume, is removed by means of siphons into the last two pans, while the superior two are again charged as before. The evaporation in the last two pans is continued for twenty-four hours, and the mother waters of a preceding crystallization mixed with it; the mixture then has a specific gravity of 1·07 to 1·08, at a temperature of from 173° to 176° Fahr. (78°·3 to 80° C.). The whole of this solution is then brought into the crystallizing tubs, A A A (Fig. 2), which are constructed of wood and lined with lead. Here the crystallization is effected. The produce of seventy-two hours' evaporation, derived each day from a battery of fourteen pans, affords $1\frac{3}{4}$ cwt. of saleable boracic acid. The production diminishes in rainy weather.

During evaporation abundant deposits of sulphate of lime are formed, and have to be removed. When crystallization ceases, the mother liquor is drawn off into tanks, and added to the solution contained in the last evaporating pans; the acid is placed in baskets, G (Fig. 2), to drain. It is then carried into the drying-room, D D, spread in layers on the floor, and turned from time to time. When it no longer moistens the hand on being pressed, it is formed into heaps and packed in casks. The drying-room is constructed of bricks, and has a double floor, between which the vapour of some *soffioni* is caused to circulate.

The largest lagoons, which are of an irregular circular form, are from 57 to 65 feet in diameter, and the smallest from 13 to 16 feet; their depth varies from 5 to 8 feet. The liquid in them attains a temperature of from 200° to 203° Fahr. (93°·3 to 95° C.).

Fig. 2.



The acid contains many impurities, due to the disintegration of the strata by the jets of steam, and the infiltrations of water. The following is WITTSTEIN'S analysis of the crude acid:—

Boric acid crystallized,................	76·494
Water................................	6·557
Sulphuric acid,.......................	1·322
Silica,................................	1·200
Sulphate of ammonium,...............	8·508
Sulphate of manganese,..............	traces.
Sulphate of magnesium, ...	2·632
Sulphate of calcium,..................	1·018
Sulphate of sodium,...................	0·917
Sulphate of potassium,................	0·369
Ferric sulphate,.......................	0·365
Sulphate of aluminium,...............	0·320
Chloride of ammonium,................	0·298
Organic matter,.......................	traces.
	100·000

Neutral borate of sodium ($NaBO_2$), is produced by heating 62 parts of crystallized boric acid, or 191 parts of crystallized borax, with 53 parts of anhydrous sodium carbonate at a heat near the melting point of silver. The unfused mass thus obtained dissolves in water with rise of temperature; and by cooling the hot, but not saturated solution, the hydrated salt crystallizes in large, oblique, rhombic prisms, with lateral angles of 130° and 70°. It has a caustic alkaline taste, and quickly absorbs carbonic acid from the air, both in the solid state and in solution; but on boiling the solutions the carbonic acid escapes. (*Watt's Dict. of Chem.* vol. i. p. 645.)

BORAX. — BIBORATE OF SODA. — *Soude boratée*, French; *Boraxsaures natron*, German; *Sodæ biboras*, Latin; *Plinias chrysocolla*, *Tincal.*—*Acid metaborate of sodium* ($Na_2B_2O_7,10\,H_2O = 2\,NaBO_2,B_2O_3,\,10\,H_2O$). The word borax is derived from the Arabic *baurak*.

Borax has been found in some mineral waters, as those of San Restituta, or Ischia, and also in the waters of certain lakes, especially those of Thibet and Persia.

Common borax is soluble in about 12 parts of cold and 2 of boiling water. Heat resolves it into a porous, friable mass, known as *calcined borax*. At a red heat it runs into a transparent glass, which on exposure to the air becomes opaque and pulverulent on the surface. Its specific gravity in this state is 2·36.

Sulphuric acid decomposes this salt, producing sulphate of sodium and boric acid. It is also decomposed by nitric and hydrochloric acids, and by most organic acids. It is often used as a blowpipe flux, vitrifying a great many of the metallic oxides, and giving with them beads of different colours; blue with cobalt, amethyst with manganese, green with chromium and copper.

Its taste is saline, cooling, and somewhat alkaline. It reacts on turmeric paper like an alkali. On being exposed to the air it effloresces slowly and slightly.

NATIVE BORAX—TINCAL. –This substance occurs in soft and brittle prismatic whitish crystals, occasionally possessing a tinge of blue or green, and varying from translucent, or nearly transparent, to opaque. Taste, feebly alkaline. Before the blowpipe it intumesces considerably, and then fuses into a transparent globule. It has been found in India, China, Persia, Ceylon, and South America. It has even been met with in Saxony. Gathered on the banks of small lakes holding it in solution, it was formerly imported into Europe in great quantity, under the name "tincal." It is always covered with an earthy incrustation, which smells of soap.

From a very remote period, native borax has been refined in Venice—whence the appellation, Venetian borax, equivalent to the purified salt. At a later period the process was introduced into the Dutch towns, and into France by the Brothers LECUYER. The operation has always been kept secret, nevertheless two different methods of purification have become known.

In one of these the impurities are separated by lime, tincal being softened in a small quantity of cold water, and stirred about with the gradual addition of about 1 per cent. of slaked lime. The turbid lime-water is poured off, and when on standing the impurities have settled down, the clear liquid is again poured upon the crystals. This process is repeated several times. In this manner the greater part of the soapy compound is removed; what still remains is separated by dissolving the crystals in hot water, and adding about 2 per cent. of chloride of calcium. Chloride of sodium is produced, and an insoluble lime soap, which is removed by straining, and the clear liquid is then evaporated to the consistence of 21° Beaumé, at specific gravity 1·17

The other process consists in placing the powdered tincal in a tub, with holes pierced in the bottom, and washing it with a solution of caustic soda of 1·034 specific gravity, as long as this passes through coloured. After draining, the crystals are dissolved in water, and 12 per cent. of soda added to precipitate the foreign matters and earths; the lye must then be evaporated to the consistence of 20° Beaumé.

In both cases, the crystallization is effected in wooden vessels lined with lead, and having the form of short inverted cones. This shape is preferred, because the deposit which may form collects in the lower narrow part, and does not interfere with the crystallization. The use of lime facilitates the clarification, but may occasion a loss by the formation of insoluble borate of calcium.

Commercial borax made from boric acid has, when used by tinsmiths, notwithstanding its greater purity, one particular fault from which that obtained from tincal is free, viz., that the crystals, when heated, split in the direction of their natural cleavage, fall to pieces, and fly off from the part required to be soldered; by which means a loss is occasioned, and the work retarded. Great precautions used in the crystallization lessen this evil; but it is more effectually remedied by the addition of a small quantity of tincal before recrystallization.

So long as borax was obtained only from tincal, its price remained very high, and in 1815 it cost from 3*s.* to 4*s.* a lb. About this time began the fabrication of the salt from the boric acid of Tuscany, and carbonate of sodium. This process is now exclusively used.

It consists in treating the boric acid with crystallized carbonate of sodium at a boiling temperature; the carbonate is decomposed, carbonic acid is disengaged, biborate of sodium is formed, and crystallizes as the liquid cools. At first view this mode of preparation appears extremely simple; nevertheless, it encountered serious obstacles in the beginning from the difficulty experienced in obtaining the crystals in a solid state and of large size. PAYEN and CURTIER overcame this difficulty, and succeeded in preparing regular supplies of borax, in firm and large crystals, by performing the crystallization on a large scale, and conducting it as slowly and regularly as possible.

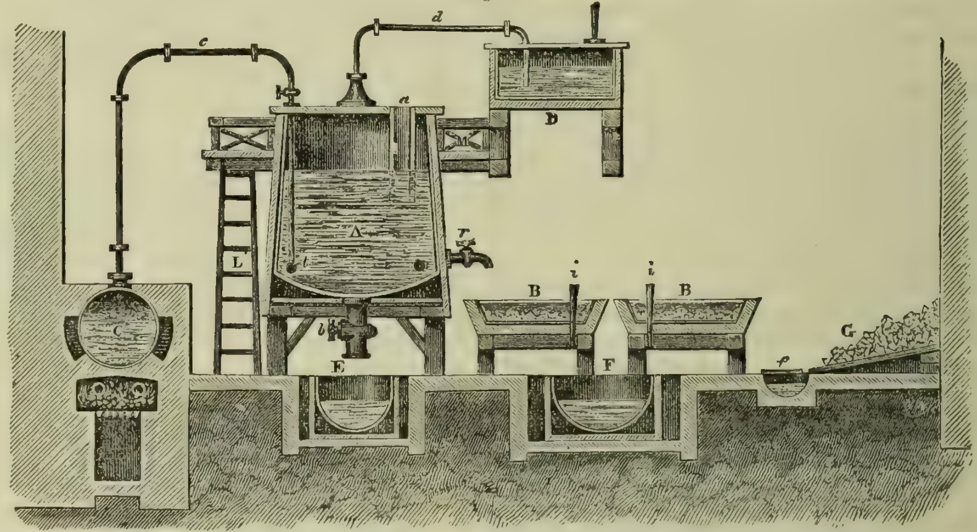
The manufacture will now be described. In a large wooden vessel, lined with lead and heated by steam, 23 cwts. of crystallized carbonate of sodium are dissolved in such a quantity of water that the whole forms nearly 2 tons when added to that produced by the condensation of the steam. The vats used for the dissolution of the soda are similar to A—Fig. 3. Steam enters the vat by a pipe, *c*, from the boiler, C; the tube reaches to the bottom of the vat, and terminates in a horizontal circular bend, *t*, which is pierced with holes for the elimination of the vapour. Two taps, *r* and *b*, serve to empty A; the opening, *a*, with its tube, is where the charge is introduced; this aperture is closed with a cover. Ladders, L, and balconies, M, are attached to the apparatus, for the convenience of the workmen to ascend and descend. When the solution of the soda is completed, the temperature is raised to 212° Fahr. (100° C.); boric acid is then added, in portions of not more than 8 to 10 lbs. at a time; the carbonate of sodium is decomposed, carbonic acid is disengaged with brisk effervescence, and biborate of sodium remains in solution. If too much boric acid were added at once, the evolution of carbonic acid would be so violent as to eject a portion of the liquor.

A little carbonate of ammonium, proceeding from the decomposition of the ammoniacal salts present in the crude acid, is always liberated along with the carbonic acid.

The apparatus is so constructed, that the gases and vapours pass through a tube, *d*, in the lid of the vat, to an adjacent condenser, D, containing sulphuric acid; sulphate of ammonium is thus produced, and the loss of a valuable secondary product prevented. To saturate the 23 cwts. of carbonate of sodium crystals, about a ton weight of Tuscan boric acid, containing nearly 10 per cent. of foreign matters, is employed.

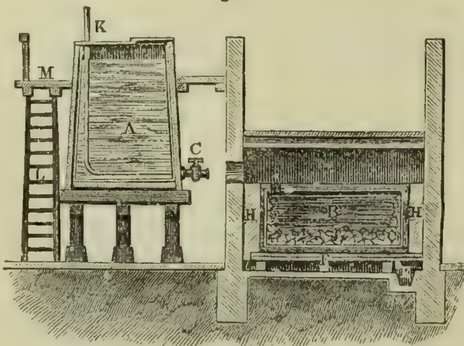
When the saturation is completed, the lye should have a specific gravity of 1·166 or 33° Twaddle. The steam is then arrested, the orifice, *a*, is closed, and the liquid is left to settle for ten or twelve hours, when the clear solution is withdrawn by the tap, *r*, into the shallow vessels, B B, lined with lead; the deposit falls through *b* into E, where it is washed, and then discarded. As soon as the crystallization is completed in the vessels, B B, the leaden plugs, *i i*, are removed, and the mother lye drawn off to the common reservoir, F, to be used for the next saturating process. The crystals are detached from the vessels, B B, and are placed upon an inclined plane or board, G, to drain: the mother liquor adhering to the crystals falls into the channel, *f*. Borax, formed in the first crystallization, must be submitted to a succeeding operation to purify it, and transform it into large crystals.

Fig. 3



Refining of Borax.—About 9 tons of the crude borax, obtained as in the preceding, are dissolved in a vat, A (Fig. 4), by means of water, heated by steam entering by the pipe, K; the solution of the salt is accelerated in a remarkable degree by placing the borax in a perforated cast-iron pan or sieve, raised by a crane, and suspended under the face of the liquid. The particles of fluid, as they become saturated and heavy, descend, leaving the less dense liquid in contact with the salt, till it becomes impregnated in like manner. When it is completely dissolved, some three or four hundredweight of carbonate of soda crystals are added to the liquor, and steam again allowed to enter, until the solution has a specific gravity of 1·66; upon which it is drawn off by the tap, C, into the crystallizing vessel, B. The inclined floor, F, below B, is made of glazed stones, and any of the mother liquor which may be thrown out of the crystallizing pan, B, by the force of the liquid descending from the vat, A, flows along it to the channel, E, where it collects. The crystallizers are large wooden vessels, lined with thick sheet-lead, and about 5 or 6 feet deep, 4 feet wide, and 20 to 30 feet long; they are situated in an external box, with which, however, they are not in contact, the intermediate space being occupied by coarse wool, saw-dust, or small coal—in fact, with any matter which is a bad conductor of heat (represented in the figure by H). The vessels are besides covered over tightly with a lid made of stout boards lined with lead, in order that the cooling of the liquor may be very gradual, as this is essential for the production of large and well-defined crystals of the salt.

Fig. 4.



The crystallization should continue from twenty-five to thirty hours, according to the external temperature; it is finished when the liquor ceases to indicate a temperature of not more than 82° to 88° Fahr. (27°·7 to 31°·1 C.); at this point the mother liquor must be abstracted by means of a siphon; a man then wipes briskly the edges of the crystals with a sponge; that done, the cover is replaced, and they are left for some hours to cool, in order that they may not become friable.

The crystals which adhere strongly to the sides of the crystallizer, are detached after drying with a chisel and heavy strokes of a mallet; they are separated from one another with a small hatchet, the small crystals taken out, and are then inclosed in cases which are made to resemble the old Dutch packages.

Prismatic borax contains 47 per cent. of water, whereas octahedral borax only contains 30 per cent.; nevertheless, consumers prefer the former, partly on account of its price, being less weight for weight, and partly as matter of habit.

Various modifications have from time to time been made in the methods employed for the preparation of borax from common crystallized carbonate of sodium and crude Tuscan boric acid. KOEHNKE gives the following directions for carrying out this process:—A solution of caustic soda is made, amounting to about 170 lbs. of 1·090 to 1·095 specific gravity, which requires on the average 50 lbs. of soda and 30 lbs. of good caustic lime, the latter mixed to a paste with four times its weight of water. When the mixture has been boiled in an iron pan, and converted into caustic lye, it is carefully covered, and after the lapse of a few hours the clear solution is siphoned off, the residue again treated with a further quantity of water, well agitated, and the clear liquid again drawn off after a few hours' rest. A further quantity of water is poured over the residue, which is subsequently removed, to be employed in washing the crystals of borax obtained.

The lyes thus obtained are boiled down to 1·090–1·095 specific gravity, and then 40 lbs. of Tuscan boric acid introduced, and the whole boiled until the lye has the spec. grav. 1·175—1·180. Upon this the liquid is poured boiling-hot into a wooden tub, which is well surrounded with woollen cloths and straw, and carefully covered to retain the heat as long as possible, so that a good and regular crystallization may be effected.

After three days the first crystallization is complete. The crystals are collected and broken, washed with dilute alkaline liquid, and placed aside; the borax lye is mixed with the wash liquors and set aside, in order that it may deposit the sulphate of calcium formed, and other impurities. As soon as the liquor has become clear, it is carefully drawn off and boiled down, during which 8 lbs. more boric acid is gradually added to it, and it is then treated as before. The remaining liquid still requires from 2 to 5 lbs. boric acid. What remains after this third crystallization may be saturated with sulphuric acid, and obtained as sulphate of soda.

The product obtained must generally be twice crystallized; for which purpose it is dissolved in 2½ parts of rain-water, the lye brought by boiling to the above specific gravity, and conveyed in a state of ebullition into a wooden vessel protected from rapid cooling. The evaporation of the residuous lye is repeated. The crystallization is always terminated within two or three days. There is no need of filtration except on the last recrystallization. The product amounts, with careful treatment, to from 60 to 62 lbs. of pure borax.

The preparation of borax from crude soda and boric acid is somewhat more difficult. A solution of caustic soda is made of 1·090 (1·095 specific gravity), which contains about 100 lbs. of crude soda and from 45 to 50 lbs. caustic lime; the lie is prepared in the same manner, and from 45 to 48 lbs. of Tuscan boric acid added to it, upon which it is concentrated to specific gravity 1·175 to 1·180; in the meantime the froth is now and then removed, and finally the whole placed aside to crystallize. To the first mother liquor from 8 to 10 lbs. of boric acid are added, and to the second 2 or 3 lbs. more; frequently, however, according to the substances employed, even as much as 10 lbs. is required. The amount must be determined by a previous examination of the borax lye. The mode of operation is precisely the same as that described in the preceding method. A greater quantity of sulphate of sodium is, however, obtained on saturating the last mother liquor with sulphuric acid. The produce in crystallized borax amounts to from 80 to 90 lbs.

Octahedral borax, $(NaBO_2)_2B_2O_3,5H_2O$, was discovered by PAYEN; it possesses the advantage that when crystallized it contains half the water of the ordinary salt. It crystallizes in a more concentrated solution than that which produces prismatic borax, and within higher limits of temperature. The operation is the same as that which has just been described, except that the solution of crude borax should have a specific gravity of 1·256 to 1·30, or 50° to 60° by Twaddle, when withdrawn into the large crystallizers. The crystallization commences at a temperature of 174° Fahr. (78°·8 C.), and the octahedral borax ceases to form at 133° Fahr. (56°·1 C.); at this point, therefore the mother waters, which yield by further cooling nothing but prismatic borax, must be quickly removed.

The crystals of octahedral borax adhere strongly among themselves; they form plates of small thickness, but very hard and sonorous. Contrary to prismatic borax, they effloresce in a very moist atmosphere, or even when immersed in water; they tend, in these circumstances, to absorb a quantity of water equal to that which they already contain, and to pass to the composition of prismatic borax. In other respects, these two descriptions of borax have the same properties.

Anhydrous Borax, $(NaBO_2)_2B_2O_3$.—This salt is granular, and of a dull white colour. Its granular state renders its use convenient for the making of glass enamel, &c. SAULTERS some years ago devised the process which follows:—About 38 parts by weight of boric acid, quite pure, crystallized, and dry, are powdered and sifted; and about 45 parts in weight of fine carbonate of sodium, reduced to a powder, added, and thoroughly mixed together. The mixture is then transferred to a room, the temperature of which is raised to about 90° to 115° Fahr. (32°·2 to 46°·1 C.). It is placed in layers or beds, of about 1 inch thick, upon wooden planks. The action of the heat upon the mixture causes the boric acid to combine with the soda, and the carbonic acid is driven off from the carbonate of sodium.

together with the superabundant water contained in it, forming borax (biborate of sodium), but without any water of crystallization. The layers should be left during from twenty-four to thirty-six hours, being occasionally stirred; after which the operation is completed and the borax is ready for the market.

Fused borax, as stated, has the property, at a high temperature, of dissolving the metallic oxides and transforming them into transparent and coloured glasses.

This remarkable property, turned to advantage in blow-pipe experiments, is likewise the basis of the chief application of borax in manufacturing operations. It is well known, indeed, that this substance is indispensable in some kinds of soldering. It is applied to prevent the oxidation of the parts intended to be joined together.

For many years borax has been introduced into the composition of fine glasses and pastes; it has also been long employed in the preparation of coatings for English porcelain.

For these latter applications the borax, provided it be pure, does not require to be crystallized; it is even preferable in the anhydrous state.

ANALYSIS.—The assay of borax may be made very easily by a process contrived by GAY-LUSSAC, and similar to that employed in alkalimetry. Since sulphuric acid completely decomposes biborate of sodium, if sulphuric acid of a known strength be employed, the quantity which will have been required to decompose a known weight of borax will indicate the quantity of soda contained in the salt; and, therefore, the proportion of borax which corresponds to that quantity of soda may be readily calculated.

The *modus operandi* is as follows:—Dissolve 100 grains of the borax under examination in about 1000 grains-measures of pure water, with the help of heat, and add thereto a few drops of tincture of litmus, so as to impart a blue tinge to the solution. This done, pour into an alkalimeter 1000 grains-measures of test-sulphuric acid, of specific gravity 1·032 (1000 grains-measures contain one equivalent of dry acid, and can, therefore, neutralize one equivalent of each base), and add it gradually to the solution of the borax. The liquid at first assumes a fine purplish hue, and at last one or two drops of the test-sulphuric acid in excess changes it into the characteristic red colour, which indicates that the point of saturation is obtained. In order, however, to detect this change of colour more easily, GAY-LUSSAC recommends the tinging of a similar quantity of water reddened by litmus, with two drops of sulphuric acid, and the comparison of the tint of this liquor with that of the solution of borax under examination. As the boric acid contained in the hot solution of borax, and which is deposited when the point of saturation is attained, interferes with the ready appreciation of the changes of colour, the solution should be allowed to cool before adding the last drops of acid. When the tinge produced in the borax liquor is exactly like that of the coloured water kept for comparison, the operator reads off the number of divisions of the test acid employed, and then calculates therefrom the value of the borax assayed. The indication is a little too high, because it is necessary to pour a slight excess of acid to produce a distinct reddening, and it is therefore customary to deduct three drops from the number indicated by the alkalimeter. The number of divisions represents the quantity of real soda contained, and from this the operator may easily calculate the quantity of the corresponding amount of boric acid.

The adulterations generally consist of common salt and alum. These impurities may be easily detected: the first, by solution of nitrate of silver, which will immediately produce a white curdy precipitate of chloride of silver, insoluble in nitric acid, soluble in a slight excess of ammonia, and which may be separated by filtering, or by decantation after it has well settled; the second, by the white bulky precipitate which ammonia produces when poured in the liquor, which precipitate is soluble in a solution of caustic potassa. The adulteration of borax with alum is sometimes so considerable, that on adding ammonia the whole solution stiffens into a thick jelly. The solution, if it contains much alum, reddens the tincture of litmus, whilst that of borax, on the contrary, renders reddened litmus paper blue again. If the borax has been falsified with one-tenth part of its weight of alum, it does not completely dissolve in water; that is to say, the liquor remains turbid, and a slight whitish sediment settles down in the glass.

Boric acid can be estimated quantitatively, in its aqueous solution, by the addition of a weighed quantity of a fixed alkaline carbonate. This method is somewhat tedious, and requires much time and attention. Carbonate of sodium is weighed in the fused state, in amount about one and a half times that of the boric acid supposed to be present in the solution. It is dissolved in the solution, and the whole evaporated at a gentle heat. At the ordinary temperature carbonic acid is not expelled from the carbonated alkalies by the free boric acid; and at a higher temperature, as also on evaporation, only in a very slight degree; it is only after the whole has been evaporated to dryness, and the dry mass is strongly heated, that any evolution of carbonic acid takes place, at which time it is necessary to be particularly careful. With a strong heat the mixture is liquid, but at a lower temperature, only tenacious. If it be fused at a white heat a constant weight is obtained on cooling, which does not vary even after long standing; but if the crucible be exposed to a moderate heat, after having been previously exposed to a strong red one, it increases in weight.

The carbonic acid in the fused mass is now estimated. If from the weight of the fused mass, the amount of soda in the carbonate of sodium originally employed be subtracted, and that of the carbonic acid which has escaped during the experiment, the quantity of boric acid is obtained with great accuracy.

The best and most accurate method of separating boric acid from bases is by means of hydrofluoric and sulphuric acids, when the boric acid is expelled as fluoride of borium, and the bases are obtained in the state of sulphates. The finely powdered borate is digested in a platinum dish with hydrofluoric acid, and pure strong sulphuric acid afterwards added. The whole is then heated at first gently, but afterwards more strongly. The boric acid goes off in the form of fluoride of boron. The base remains as sulphate, which is estimated, and the boric acid determined by difference. Since boric acid does not form with any metal a compound which is entirely insoluble in water, no direct method of estimating this acid is as yet known. The only compound, by means of which it may be proximately separated, is the borofluoride of potassium; this salt is very sparingly soluble, and resembles the silicofluoride of potassium, and like it is insoluble in alcohol. It is more soluble in a solution of chloride of ammonium than in pure water. A great number of experiments has shown that it is not possible to separate boric acid, quantitatively, as borofluoride from its solution.

BORON.—This element was discovered in 1808 by GAY LUSSAC and THÉNARD, and about the same time by DAVY. The probability of its belonging to the same group as silicon and carbon was insisted on by DUMAS in 1840; and the fact was afterwards established by ST. CLAIRE DEVILLE and WÖHLER.

Boron has been obtained in three different forms, viz., amorphous, graphitoïdal, and adamantine.

Amorphous Boron.—GAY LUSSAC, THÉNARD, and DAVY, obtained this substance by the action of potassium at a high temperature upon anhydrous boracic acid (now termed boric oxide, or boric anhydride (B_2O_3), by hydration boric oxide is converted into boracic acid, *i.e.*, boric acid, or hydrogen borate, H_3BO_3). The boracic acid was fused in a glass tube with an equal weight of potassium in small pieces; on boiling the fused mass with very dilute hydrochloric acid, washing with water and drying, a very small quantity of boron was obtained.

R. D. THOMSON mixed the potassium and anhydrous boracic acid together only after the former had been freed as completely as possible from hydrate, and the latter had been most completely dried; by this means he increased the product.

SAINT CLAIRE DEVILLE and WÖHLER, however, were the first chemists to produce boron in any considerable quantity. In the "Ann. de Chimie," vol. lii. p. 64, they describe their process thus:—We prepare boron by a process so simple and rapid that we have been able to use nearly a kilogramme (2·2 lbs.) of the element in experiments upon its nature and properties.

Ten parts of fused boracic acid coarsely powdered are mixed with 6 parts of sodium in small pieces, and the whole heated to redness in an iron crucible, and the mass immediately covered with 4 to 5 parts of common salt, and the crucible closed with an iron lid.

Great care must be taken to avoid the introduction of any siliceous matter, as in that case silicon would be at the same time produced, and would be hard to separate.

The addition of the sodium chloride is to render the slag of borax and boracic acid more fusible.

The reaction is complete so soon as a slight crepitation is perceived. The fused mass is then agitated with an iron rod and poured into a deep vessel containing water, strongly acidulated with hydrochloric acid.

The mixture is rapidly disintegrated by the acidulated water, and the boron for the most part sinks to the bottom of the vessel. The process is repeated several times, the same water being used each time, until it becomes strongly heated by successive additions of the melted flux. The whole is then filtered and the boron washed, first with acidulated water, and afterwards with pure water. The last washings are apt to contain boron. From these it can be thrown down by addition of hydrochloric acid as a flocculent very combustible powder. (To avoid this loss it is better to wash with a weak solution of sal-ammoniac, instead of pure water, afterwards removing the ammonium salt with alcohol.)

The boron is then dried in the air on porous tiles at the ordinary temperature. The slightest elevation of temperature suffices to induce incandescence, upon which the boron takes fire, and burns into boric oxide (anhydrous boracic acid.)

Amorphous boron is a greenish powder without taste or smell, but which stains the fingers; it is a non-conductor of electricity. Heated in *vacuo*, or in gases with which it does not unite, it undergoes no change even at a white heat. In pure water it is slightly soluble, but not in water containing acids or salts. Burnt in oxygen, boric anhydride (B_2O_3), its only known combination with oxygen, is produced. Amorphous boron decomposes sulphuric acid when heated with it, and nitric acid even in the cold, forming boric acid. It also decomposes all the salts of the alkaline metals, sometimes with incandescence, and in the case of the nitrates with explosion.

Graphitoidal Boron.—Chloride of boron is first prepared by passing chlorine gas over amorphous boron in a combustion tube gently heated. The vapours of the chloride are then conveyed through a caoutchouc connecting tube to a porcelain tube heated to bright redness, within which is a small boat containing aluminium. A certain quantity of chloride of aluminium is immediately formed and volatilized, and at the same time boride of aluminium takes the place of the metallic aluminium.

Aluminium boride can also be obtained by heating together aluminium, fused borax, and cryolite, with a flux of potassium and sodium chloride. A large excess of aluminium is required beyond that necessary for the reaction itself.

Or, by fusing together 15 parts of anhydrous boracic acid, 10 of fluor spar, and 2 of aluminium.

On dissolving the aluminium boride, prepared by one of these methods, in hydrochloric acid, or soda solution, thin hexagonal tablets of graphitoidal boron make their appearance.

Graphitoidal boron is semi-metallic, resembling crystalline ferric oxide; it has a coppery lustre, and is completely opaque. Heated to redness in air it neither oxidizes nor undergoes any other change. It is insoluble in most acids, and in all alkalies.

Adamantine Boron.—This, the third state of the element, is to amorphous boron what the diamond is to common charcoal. It is prepared by the mutual action of aluminium and boracic anhydride.

A charcoal crucible with a close-fitting cover is fitted within a plumbago crucible. In the inner vessel are put 80 grammes of aluminium, and 100 grammes of fused boracic acid in small pieces, the lids closed, and the whole placed in a blast furnace of sufficient power to melt nickel. The temperature is maintained at its maximum for about five hours, the furnace being meantime well clinkered. After cooling, the crucible is broken, and within it are found two distinct layers, the one vitreous and consisting of boracic acid and aluminium, the other a metallic, iron-grey, spongy mass. This is aluminium penetrated throughout its mass with crystals of the diamond-like boron.

The metallic part of the contents are then treated with boiling soda liquor, which dissolves the aluminium; next with hydrochloric acid to get rid of the iron; and finally with a mixture of hydrofluoric and nitric acids to extract any possible traces of silicon. The crystals of boron are, however, still mixed with graphitoidal boron and aluminium; the former is separated by levigation, the latter by careful selection.

Adamantine boron has been heated to the fusing point of iridium without showing any signs of change. It resists oxygen up to the temperature at which the diamond burns; it then oxidizes and becomes coated with a film of boracic acid, which stops all further action.

Chlorine, on the other hand, acts upon it with great energy at a dull red heat, converting it into vapour of chloride of boron.

Heated before the blowpipe on platinum foil, boron immediately determines the fusion of the platinum, forming with it a boride.

The specific gravity of crystalline boron is 2·68. These crystals refract light very powerfully, and are nearly as hard as the diamond. They are octahedra, belonging to the pyramidal or square prismatic system.

Boric Oxide—*Boric Anhydride. Anhydrous boric (or boracic) acid. Oxide of boron* (B_2O_3).—This is the only known compound of boron with oxygen.

It is readily formed by fusing boric (*i.e.*, boracic) acid, which is the hydrated oxide. The water volatilizes, and a glassy mass is produced, which is known as vitreous boric or boracic acid. According to Dumas this boric glass cracks spontaneously on cooling, each fracture being accompanied by a flash of light. The specific gravity is 1·83.

Boric anhydride has a bitter taste, is inodorous, and is very soluble in water, forming boric acid. It dissolves also in alcohol, producing a solution which burns with a green flame.

The volatile product which is formed under these circumstances is in reality a boric ether. The presence of a metallic oxide interferes with the colouration, because in that case no ether is formed.

Boric anhydride at its fusing point unites directly with metallic oxides. It decomposes, by fusion with them, carbonates, nitrates, sulphates, and salts of all acids more easily volatilized than itself. Boric oxide loses its transparency when exposed to the air, and becomes covered with a coating of its hydrate, boric acid.

BRASS.—See Copper Alloys.

BREAD.—*Pain*, French; *brod*, German; *panis*, Latin. The material part of grain, which by conversion into bread is rendered useful as a nutritive substance, is composed of nitrogenous substances (chiefly vegetable fibrin) and non-nitrogenous substances, (principally starch), with varying quantities of dextrin and sugar, and inorganic salts, which are mostly phosphates. Of these the nitrogenous constituents chiefly produce blood, and are therefore the most nutritive; while the organic portion of the latter constituents is almost exclusively devoted to maintaining the heat of the body, and is consequently called respiratory food.

Horsford, in investigating the relative values of different substances as articles of food, tabulated the annexed results for various kinds of wheat, which show the quantity of nitrogen in each when in the fresh state; *i.e.*, their relative nutritive power:—

Horsford.	Per centage of nitrogen	Equivalents or weights for an equal amount of nutritive power.	Per centage of water.	Practical equivalents.
Talavera wheat from Hohenheim,	2·59	100	15·43	100
Whittington, ...	2·63		13·93	
Sandomierz, ...	2·69		15·48	
Wheaten flour from Vienna, No. 1,	3·00	90	13·85	—
" " " 2,	2·12		13·65	
" " " 3,	3·44		12·73	
Common winter wheat.........	2·79	104	13·80	102
One-grained wheat—Triticum monococcum—from Giessen,	2·07	128	14·40	124

The fourth column in the above table indicates the practical equivalents of the nutritive powers of these substances, as ascertained by Boussingault's experiments on the feeding of cattle.

Wheat contains more nitrogen than any of the other cereals. As cultivated in this country, it is of several kinds, which take their rise from that known as *Triticum vulgare;* there are two other sorts, the *Triticum æstivum*, or summer wheat; and the *Triticum hibernum*, or winter wheat; and these again, from intermixture and various other causes, are broken up into separate species. *Triticum æstivum* is generally tilled in spring, and the proper season for sowing the winter wheat is in autumn.

Wheat is composed of an exterior integument or shell, covering the nourishing matters; the shell constitutes from 14 to 16 per cent. of its weight when the grain is good, but the proportion is greater as it is poorer. It generally happens that no more than the one-tenth, and frequently only about one-eighth or one-ninth, is removed by grinding.

The floury part of the grain is composed of vegetable fibrin, gluten, albumen, starch, dextrin, glucose, water, and inorganic salts. These constituents are divided into the nitrogenous, which embrace the grape sugar, vegetable fibrin, albumen, and oil; and the non-nitrogenous, which include the starch sugar, gum, and inorganic salts. Flour, when kneaded with a little water—or better, when a small stream of water has been directed upon it, whilst supported by a thin cloth—becomes entirely disintegrated, in consequence of the soluble portions being carried away in the water, while the small starch granules are mechanically taken up, and there remains a tough substance unaffected by water. At first the water, as it percolates through the cloth, has a milky appearance, and the matter upon the filter or cloth becomes shorter and more porous up to a certain period; as the filtrate passes off clearer, the remaining mass agglutinates into a compact body, which is known as *crude gluten*, but really consists of vegetable fibrin, held together by *gluten* or *gliadin;* it also contains some fatty matter. Crude gluten does not swell when treated with water, but combines with a definite quantity, acquiring a certain degree of tenacity, which, however, is not increased by further addition of water; it is not liable to decomposition for some time, and is very adhesive to solid bodies, such as the sides of vessels, paper, linen, &c., whenever it comes in contact with them; it may, however, be detached by immersion in water, or, in the case of linen or cloth, by moistening the contrary side. Boiling alcohol readily separates the crude gluten into a soluble and an insoluble substance; the insoluble is pure vegetable fibrin, and the soluble contains vegetable gliadin, to which the adhesive property of the crude gluten is attributed: by treating the latter with ammonia, the gliadin is dissolved and the fibrin remains. No cereal has so much gliadin as wheat; hence the superior tenacity of wheaten dough.

The results obtained by PAYEN show the amount of gluten to be from 9 to 22 per cent.; and during his investigation he discovered the interesting fact, that the quantity of gluten diminishes towards the heart of the seed. From this the conclusion follows, that the part of the grain in immediate contact with the integumental coating, being richest in this principle, is more nourishing as food than any other portion of the wheat grain. FURSTENBERG found corresponding results when analyzing wheat bran: it contained—

Flour, Organic		Gluten,	10·84	12·44
		Albumen,	1·60	
		Starch,	22·66	41·06
		Gum,	5·28	
		Oil or fat,	2·82	
		Water,	10·30	
Husk	Organic, or Ligneous matter,			43·98
	Inorganic	Chloride of potassium,		0·23
		Sulphate of potassa,		0·24
		Phosphate of magnesia,		0·93
		Carbonate of lime,		0·37
		Silica,		0·75
				100·00

The older chemists ascertained the amount of gluten, by mechanical washing, to be from 8 to 24 per cent., and the starch from 66 to 67 per cent.

Could the operations of the miller be brought to that state of perfection which would insure the separation of the husks, a flour containing 30 per cent. of gluten and albumen—a quantity two-fifths to one half greater than the yield from ordinary flour—would be obtained. From this it is evident that a great waste of valuable ingredients is incurred by the present process of grinding, which leaves much of the most nutritive part of the food (*i.e.*, its nitrogenous constituents) in the bran, which is composed of—

	Per cent.
Water,	13·1
Albumen—coagulated,	19·3
Fatty matter,	4·7
Husk and a little starch,	55·6
Saline matter—ash,	7·3
	100·0

Considerably more oil is found in the husk than in the interior of the grain, as the table appended shows:—

	Oil per cent.
Fine flour,	1·05
Boxings,	2·36
Pollard or sharps,	3·56
Bran,	3·25

Starch is present in considerable quantities in wheat flour, and indeed in all the cereals; it deposits from the solution obtained on washing the dough, as before noticed, with water. Some time is allowed for the starch to separate completely, when it forms a concrete granular cake on the bottom of the vessel. Besides starch, albumen, glucose, and dextrin, similar principles and inorganic salts are found in the aqueous extract.

JOHNSTON'S table of the relative quantity of ash or mineral constituents, yielded by different samples of ground wheat from the localities named, is annexed:—

	Ash in a hundred parts of dry			
	Fine flour.	Boxings	Sharps.	Bran.
Sunderland Bridge, near Durham,	1·24	4·0	5·8	6·9
Kimblesworth,	1·15	3·8	4·9	6·7
Houghall,	0·96	3·0	5·6	7·1
Plawsworth,	0·93	2·7	5·5	7·6
Stettin,	1·01	4·5	6·2	6·9
Odessa,	1·01	4·9	6·6	8·0

The subjoined table represents the inorganic constituents of several varieties of wheat, according to recent analyses performed by different chemists.

When wheat grain is incinerated, the amount of the ash remaining is about 2½ per cent. from dry grain, but only 2 per cent. is obtained when the grain is fresh; of this residuary ash the preceding table shows the composition in 100 parts. The apparent irregularity observed in the composition of the ash from various samples, is occasioned by the well-known property of plants, of assimilating different but analogous constituents from the soil, when the true body peculiar to the grain is wanting, either through exhaustion of the soil or otherwise.

TABLE SHOWING THE COMPOSITION OF THE ASHES OF WHEAT, ACCORDING TO RECENT ANALYSES.

	Plants, or parts of plants	Ashes in 100 parts of crop as taken from ground	Ashes in dry plants, when all the water is artificially removed.	Potassa.	Soda.	Magnesia.	Lime.	Phosphoric acid.	Sulphuric acid.	Silica.	Peroxide of iron.	Chloride of sodium.	Locality of plant.	Analyst.
Wheat of Foreign growth.	Grain, red......	—	—	21·87	15·75	9·60	1·93	49·32	0·17	—	1·96	—	Giessen.	Will and Fresenius
	Grain, white, ..	—	—	33·84	—	13·54	3·09	49·21	—	—	0·31	—	Giessen.	"
	" ..	—	—	25·90	0·44	6·27	1·92	60·30	—	3·37	1·33	—	Leipsic.	Schmidt.
	" ..	—	—	6·43	27·79	12·98	3·91	46·14	0·27	0·42	0·50	—	[1]Holland.	Bichon.
	" ..	—	—	24·17	10·34	13·57	3·01	45·53	—	1·01	0·52	—	Solz, Hesse-Cassel.	Thon.
	" ..	—	—	30·12	—	16·26	3·00	48·30	1·01	1·31	—	—	Bechelbronn, Alsace.	Boussingault.
	" ..	1·55	1·74	32·39	2·32	13·94	3·47	43·47	0·35	3·05	0·97	—	France.	Way and Ogston.
	" ..	1·50	1·68	30·30	1·00	14·28	3·17	45·80	—	4·48	0·89	—	Odessa.	"
	" ..	1·7	1·88	35·77	9·06	14·09	2·05	34·44	0·24	4·00	—	—	Adrianople.	"
	" ..	1·97	2·19	36·60	0·53	11·12	4·34	41·03	0·18	4·97	1·18	—	Egypt.	"
Hopeton wheat, grown in England.	" ..	1·81	2·05	33·15	—	12·71	3·20	47·00	0·24	2·84	0·60	—	[2]Cirencester.	"
	" ..	1·51	1·69	33·00	2·07	13·99	2·82	46·18	0·48	1·42	—	—	[3] "	"
	" ..	1·48	1·70	27·06	4·08	13·57	4·29	41·22	1·91	5·91	1·36	—	[4] "	"
	" ..	1·56	1·72	32·24	4·06	10·94	2·06	45·73	0·32	2·28	2·04	0·27	[5]Dorset.	"
	" ..	1·63	1·84	29·92	6·08	12·43	1·83	45·30	0·59	4·43	1·76	0·64	[6] "	"
	" ..	1·61	1·81	36·43	4·62	13·26	1·32	39·97	0·15	4·23	—	—	[7]Gloucestershire.	"
	" ..	1·63	1·81	32·05	3·38	9·32	4·43	47·33	—	3·05	0·35	—	[8] "	"
	" ..	1·71	1·94	34·51	1·87	11·69	1·80	43·98	0·21	5·63	0·29	—	[9] "	"
	" ..	1·69	1·92	30·32	0·07	12·38	2·51	49·22	0·18	3·60	0·08	1·60	[10] "	"
	" ..	1·76	2·01	32·14	2·14	9·67	8·21	44·44	—	3·29	0·08	—	[11] "	"
Red-straw white wheat, grown in England.	" ..	1·70	1·91	31·00	2·54	9·53	1·45	40·91	0·08	9·71	3·34	0·34	[12]Sutton Waldron.	"
	" ..	1·72	1·95	29·75	0·64	13·75	3·27	49·58	0·60	2·14	0·23	—	[13]Gloucestershire.	"
	" ..	1·73	1·97	29·91	1·87	14·05	3·39	47·44	—	2·63	0·67	—	[14] "	"
	" ..	1·61	1·81	30·13	1·25	11·46	6·37	47·38	0·07	2·76	0·07	—	[15] "	"
	" ..	1·60	1·80	30·02	3·82	13·39	1·15	46·79	—	3·89	0·91	—	[16] "	"
	" ..	1·90	2·13	29·17	2·20	14·22	5·05	46·61	0·44	2·17	0·09	—	[17] "	"
	" ..	1·73	1·96	26·70	2·12	12·76	6·78	46·99	0·24	2·05	2·32	—	[18] "	"
	Old red Lammas wheat,	1·84	2·10	34·26	4·53	9·56	3·21	40·57	0·32	5·46	2·06	—	[19]Wantage.	"
	Spalding wheat,......	1·81	2·05	29·76	5·26	11·06	2·88	48·21	0·11	2·23	0·23	—	[20]Cirencester.	"
	Creeping wheat,......	1·73	1·95	31·18	2·42	12·35	1·50	46·49	0·61	5·20	0·22	—	[21]Hackness.	"
	" ..	1·65	1·85	28·89	1·40	13·06	6·76	45·64	1·55	2·55	0·11	—	[22] "	"
	" ..	1·71	1·91	30·94	1·28	12·74	3·72	48·53	—	1·34	1·40	—	[23] "	"
	Mean of the 32 analyses	1·67	1·93	29·97	3·90	12·30	3·40	46·00	0·33	3·35	0·79	0·90	"	"

REMARKS.

1. This wheat being grown near the sea, part of the potassa is substituted by soda.
2. Grown on calcareous stone-brash on the oolite.
3. Grown on calcareous brash and clay
4. The seed from which the two previous specimens were grown
5. Loamy soil, on the clay below the chalk.
6. Calcareous soil.
7. Siliceous soil lying on limestone.
8. Clayey soil on the Silurian rocks.
9. Sandy soil on the Silurian rocks.
10. Clayey soil on the Silurian rocks.
11. Sandy soil on old red sandstone.
12. Loamy soil on the green-sand
13. Sandy loam on the old red sandstone.
14. Do. do.
15. Calcareous soil on the mountain limestone.
16. Clayey loam on Ludlow rock (?)
17. Sandy calcareous soil—Silurian
18. Calcareous clay on magnesian limestone.
19. Very calcareous soil on the chalk
20. Calcareous stone-brash; great oolite.
21. Soil, clayey sand.
22. Do. do.
23. Soil, calcareous rubble, Oxford clay.

The proportionate quantities of gluten, albumen, starch, fibrin, &c., in wheat, is exhibited in the annexed analyses, the grain being dried at 212° Fahr. (100° C.).

	Wheat from Hohenheim.			Triticum monococcum from Giessen.	Wheat from Vienna.		
	Talavera.	Whittington.	Sandomierz.		No 1.	No. 2.	No. 3.
Gluten and albumen, ...	16·52	17·09	17·15	13·20	19·15	13·53	21·93
Starch,..............................	56·25	52·45	53·37	54·63	65·68	67·17	57·45
Fibrin, gum, sugar,..................	24·53	26·53	25·52	29·80	14·09	18·20	20·58
Ash,.................................	2·80	3·13	2·40	2·10	0·70	0·66	1·11
	100·10	99·20	98·44	99·82	99·62	99·56	101·07
Per centage of moisture in the grain,....	15·43	13·93	15·48	14·40	13·83	13·65	12·73

The following are the results of analyses of wheat by PELIGOT:—

	No 1. White Flemish wheat 1841.	No 2. Hardy wheat 1843.	No 3. Touselle blanch from Provence.—1842.	No 4. Odessa wheat Poland.	No 5. Blé Herisson. 1842.	No 6. Poulard roux. 1840.	No 7. Poulard bleu Conique 1844.	No 8. Poulard bleu Conique. Very dry year—1840	No 9 Mitudin du Midi.	No. 10. Polish wheat. 1844.	No. 11. Hungarian wheat 1845.	No 12. Egyptian wheat.	No 13. Spanish wheat.	No 14 Tanga rock wheat
Water,..............................	14·6	13·6	14·6	15·2	13·2	13·9	14·4	13·2	13·6	13·2	14·5	13·5	15·2	11·8
Fatty matters, ...	1·0	1·1	1·3	1·5	1·2	1·0	1·0	1·2	1·1	1·5	1·1	1·1	1·8	1·9
Nitrogenous matter insoluble in water,..	8·3	10·5	8·1	12·7	10·0	8·7	13·8	16·7	14·4	19·8	11·8	19·1	8·9	12·2
Soluble nitrogenous matter—albumen,..	2·4	2·0	1·8	1·6	1·7	1·9	1·8	1·4	1·6	1·7	1·6	1·5	1·8	1·4
Soluble non-nitrogenous matter—dextrin,	9·2	10·5	8·1	6·3	6·8	7·8	7·2	5·9	6·4	6·8	5·4	6·0	7·3	7·9
Starch,.............................	62·7	60·8	66·1	61·3	67·1	66·7	59·9	59·7	59·8	55·1	65·6	58·8	63·6	57·9
Cellulose,..........................	1·8	1·5	—	—	—	—	1·5	—	1·4	—	—	—	—	2·3
Saline matter,......................	—	—	—	1·4	—	—	1·9	1·9	1·7	1·9	—	—	1·4	1·6

The cellulose and ashes, or saline ingredients, are to be deducted from numbers 3, 5, 6, 11, 12, and cellulose only from numbers 4, 8, 10, and 13.

Having thus far dwelt in detail upon wheat, on account of its greater importance in bread-making, it will be necessary to give a short sketch of the other cereals, which are also used as food in the form of bread. These are Rye, Barley, Oats, Indian corn, Rice, &c.

RYE.—This grain is very similar to wheat in its physical properties. It is the seed of the *Secale cereale*, resembling wheat in form, but rather elongated. Its cultivation in this country is not carried on to any great extent, but it forms the staple tillage in the Northern European provinces, where the soil, being sandy, is well adapted for its production.

This cereal in its cultivation is subject to many casualties, which prevent the formation of the grain; among these the "ergot" is most destructive.

In an agricultural point of view, very little has been done towards gaining a knowledge of the nature of this substance, and the treatment which affects its growth. Many consider it as a morbid alteration of the *ovarium* of the grain, caused by the puncture of an insect of the genus *musca*, and which deposits a very dark-coloured liquid. Some toxicologists rank the ergot of rye among narcotico-acrid poisons: others regard it as a poison *sui generis*. Its chronic effects have occasionally been witnessed on the Continent in an epidemic form, and they have, in some instances, been distinctly traced to its admixture with rye bread. BONJEAN knew of two cases in which spontaneous gangrene was induced by bread containing this deleterious substance. Ergot of rye is extensively employed by accoucheurs to aid, and, indeed, to bring on parturition.

When rye is ground, it produces a flour like that of wheat, but considerably darker in colour. The reason of this seems to be that more of the husk of the grain is carried through the mill and passes into the flour. The analysis of rye flour is conducted in a similar manner to that of wheat flour. On washing with water the pasty mass of rye flour, however, no residue remains, as it is entirely carried off mechanically in the solution; hence, the gluten of rye flour cannot be separated from the starch, as can be done with that of wheat. The dissimilarity of these grains in respect to the behaviour of the flour with water, seems to depend upon the different natures of their gluten; according to HELDT, the gluten of rye contains very little fibrin, but a nitrogenous substance, which he names vegetable gelatin.

The analyses of rye given below, show the nourishing power of this grain:—

	Rye flour.			Rye and bran.		
	Einhot.	Greif.	Boussingault.	Flour.	Furstenberg.	Bran.
Gluten,	9·48	12·8	10·5	3·96	Organic matter,	6·18
Albumen,	3·28	3·0		3·34	Chloride of potassium,	0·01
Starch,	61·07	58·8	64·0	65·32	Phosphate of magnesia,	0·39
Sugar,	3·28	10·4	3·0	—	Silica,	0·12
Gum,	11·09	7·2	11·0	3·78		
Woody fibre,	6·38	—	6·0	—		6·70
			Fat.		Water,	14·98
Acid unexamined, loss,	5·62	7·8	3·5	1·92	Total constituents of the flour,	78·32
	100·20	100·0	98·0	78·32		100·00

More accurate results may be calculated as follows, from the elementary analysis of HORSFORD and KROCKER:—

	Dried at 212° Fahr.					
	Rye flour from Vienna.		Rye flour from Hohenheim.		Buck-wheat flour from Vienna.	Tartarian buck-wheat from Hohenheim.
	No. 1.	No. 2.	Schilt.	Standen.		
Gluten and albumen,	11·92	18·60	17·73	15·76	6·88	9·94
Starch,	60·91	54·48	45·09	47·42	65·0[illegible]	44·12
Woody fibre, gum, sugar,	24·74	24·49	35·77	35·25	26·47	46·26
Ash,	1·33	1·07	2·43	2·37	1·09	2·30
	98·90	98·73	101·02	100·80	99·49	102·62
Moisture in fresh substance,	13·78	14·68	13·94	13·82	15·12	14·19

The inorganic constituents of the ashes of rye are—

	Rye.		
	1. From Giessen.	2. From Cleves.	3. Kidderminster.
Potash,	31·89	11·43	33·83
Soda,	4·33	18·89	0·39
Lime,	2·84	7·05	2·61
Magnesia,	9·86	10·57	12·81
Ferric oxide,	0·80	1·90	1·04
Phosphoric acid,	46·03	57·81	39·92
Chloride of sodium,	trace	—	—
Silica,	1·42	0·69	9·22
Sulphuric acid,	0·17	0·51	0·18
Charcoal, sand, &c.,	2·66	—	—
	100·00	—	100·00

The first and second samples were analysed by WILL, FRESENIUS, and BICHON, and the third by WAY and OGSTON.

BARLEY.—The barley mostly cultivated in Great Britain is the species known as *Hordeum distichon*, or two-eared barley. As met with in the market, the seeds are usually enveloped in their *palee* or husk; stripped of this it forms *Scotch barley*, and when the latter is rounded by peculiar means it bears the name of *pearl barley*.

The proportion of nitrogenized matter in barley is much less than in wheat; therefore the crude gluten is rather deficient, so much so that very little remains upon washing the dough with water. The annexed analyses of this grain by EINHOF and BOUSSINGAULT show the relative proportions of water, husk, and flour in 100 parts of the grain:—

	Water.	Bran.	Flour.	
Common barley,..	11·0	19·0	70·0	EINHOF.
Naked barley,...	10·0	17·0	73·0	"
Barley,.........	13·0	18·0	69·0	BOUSSINGAULT.

Barley contains about 6·24 per cent. of gluten and albumen, and 69·5 of starch, gum, and sugar. FROMBERG gives the relative proportion of nitrogenous matter in hard and soft barley, which he calculated, from the nitrogen obtained, as follows:—

Soft, or malting barley,................	10·93
Flinty, or hard barley,.................	8·03

OATS.—Another of the cereals, and to which reference has been made, is the oat, a plant extensively cultivated in this kingdom. There are several varieties; that which is grown in this country is the kind known as the *Avena sativa.* The oat is a seed different in appearance and composition from those grains already spoken of, though the same substances are peculiar to all of them. It is of an elongated conical shape, and is inclosed in a thick husk, deprived of which it constitutes what are termed "groats;" these, crushed, produce what is known as "Embden groats," and when finely ground, oat flour or meal of a yellowish white colour. Though this does not form a dough or paste with water like wheat flour, it nevertheless contains a large amount of nitrogenous matter, which exists in the form of a peculiar body, *avenin,* similar to and probably identical with legumin.

The annexed analyses of oats give the relative amount of water, flour, and bran:—

	Water.	Bran.	Flour.
Oats,..............	—	34	66
"	21	18	62

NORTON gives the average analyses of eight samples of Scotch oats which he examined, in the annexed numbers; namely, grain, 76·28; and husk, 23·68. The maximum of husk in his analyses was 28·2, and the minimum 22·0.

The composition of French oats, including the husk, according to BOUSSINGAULT, is as follows:—

	Centesimally represented.
Starch,..............................	46·1
Gluten-avenin, albumen,................	13·7
Oil,.................................	6·7
Sugar,...............................	6·0
Gum,.................................	3·8
Husk-ash and loss,....................	23·7
	100·00

Previous to this analysis the meal was dried at 230° Fahr., and the loss of water was found to be 20·8 per cent. The investigations relative to this subject performed by Professors KROCKER, HORSFORD, and THOMSON, afford the following results:—

ANALYSES OF BARLEY AND OATS BY KROCKER, HORSFORD, AND THOMSON, DRIED AT 212° FAHR.

	Krocker and Horsford.		Krocker and Horsford.		Thomson.
	Winter Barley, Hohenheim.	Jerusalem Barley, Hohenheim.	Kamschatka Oats, Hohenheim.	White Oats, Hohenheim.	Barley, Scotland,
Gluten and albumen, ..	17·70	14·72	17·99	12·17	15·24
Starch, ...	38·31	42·34	37·41	84·74	39·86
Husk, gum, sugar, ...	42·33	42·46	45·67		46·19
Ash,..................	5·52	2·84	4·14	3·09	3·26
Moisture in the grain,..	13·80	16·79	12·94	9·46	12·71

Those inorganic compounds which are necessary for the production of bone and the other inorganic parts of the animal body are supplied by the oat. The following analyses of the ashes of oats, by Messrs. WAY and OGSTON, demonstrate this point:—

ANALYSES OF THE ASH OF OATS BY MESSRS. WAY AND OGSTON.

	Hopeton Oats. Grain.	Potato Oats. Grain.	Polish Oats. Grain.	Polish Oats. Grain.	Unknown. Grain.
Potassa,..............................	17·80	19·70	24·30	16·35	13 97
Soda,.................................	3·84	1·35	3·84	5·27	1·50
Lime,.................................	3·54	1·31	3·54	8·35	4·22
Magnesia,.............................	7·33	8·25	7·33	5·90	8 82
Sesquioxide of iron,..................	0·49	0·27	0·69	0·09	0·36
Sulphuric acid,.......................	1·10	0·10	1·74	4·01	0·13
Silica,...............................	38·48	50·03	41·86	43·20	49·44
Carbonic acid,........................	—	—	—	0·59	—
Phosphoric acid,......................	26·46	18·87	14·49	16·19	21·53
Chloride of sodium,...................	0·92	0·07	0·45	—	—
Loss,.................................	0·04	0·05	1·76	0·05	0·03
	100·00	100 00	100·00	100·00	100·00
Percentage of ash in the dry substance,........	2·50	2·73	2·97	3·80	3·12
Percentage of ash in the fresh substance,......	2·27	2·45	2·65	3·31	2·75

INDIAN CORN.—This grain, as it comes to the market, is generally of a yellowish colour, though some varieties are white; the shape of the grain is somewhat rectangular, but broader and thicker at the top; the nutritious portions are enveloped in a very thick covering.

Indian corn does not thrive in this country, but grows luxuriantly in America, and also in southern Germany and other warm climates.

When the dough of Indian corn is washed with water, like that of wheat, a glutinous residue is left, different, however, from the gluten of wheat, and characterized by its solubility in alcohol. The following elementary analyses are different from the preceding in the amount of nutritious matters :—

	Indian meal from Hohenheim.	Indian meal from Polenta, Vienna.
Gluten and albumen,	14·66	13·65
Starch,	66·34	77·74
Husk, sugar, gum, fat,	18·18	7·16
Ash,	1·92	0·86
Water in fresh substance,	14·96	13·36

Indian corn contains more fatty matter than any other grain, and as much as 4½ per cent. of a yellow thick fluid oil.

Maize, or Indian corn, yielded 14 per cent. of water, and the dried grain upon analysis by PAYEN :—

	Centesimally.
Husk,	5·9
Gluten,	12·3
Starch,	71·2
Sugar and gum,	0·4
Fatty matter,	9·0
Saline matter, or ash,	1·2
	100·0

The ash of Indian corn is composed of—

	Grown in the U. States. Fromberg.	Bechelbronn. Letellier.
Potash,	26·63	30·8
Soda,	7·54	
Lime,	1·59	1·3
Magnesia,	15·44	17 0
Phosphoric acid,	39·65	50·0
Sulphuric acid,	5·54	—
Silica,	2·09	0·8
Ferric oxide,	0·60	—
Loss,	0·92	0·1
	100·00	100·0

RICE.—Two specimens of rice, examined by D'ARCET and PAYEN, the one from Lombardy and the other from Carolina, contained 13½ per cent. of moisture and 12 per cent. of nitrogenous matter; the method of analysis pursued, however, was calculated to give too much of the latter.

JOHNSTON found the composition of a species of unhusked rice to be—

Husk,	20·91
Grain,	79·09
	100·00

Five varieties of rice, freed from husk, gave respectively the annexed proportions of water and ash :—

	Water.	Ash.
Madras rice,	13·5	0·85
Bengal rice,	13·1	0·45
Patna rice,	13·1	0·36
Carolina rice,	13·0	0·33
Carolina rice flour,	14·6	0·35

According to PAYEN, dry rice contains—

	Centesimally.
Starch,	86·9
Gluten, &c.,	7·5
Fatty matter,	0·8
Sugar and gum,	0·5
Epidermis,	3·4
Saline matter—ash,	0·9
	100·0

The following analysis of the inorganic constituents of rice shows the nature of the mineral substances contained in this grain :—

	Rice grain from Bechelbronn.	Husk.
Potash,	18·48	1·60
Soda,	10·67	1·58
Magnesia,	11·69	1·96
Lime,	1·27	1·01
Phosphoric acid,	53·36	1·86
Sulphuric acid,	—	0·92
Silica,	3·35	89·71
Ferric oxide,	0·45	0 54
	99·27	99·18

Rice contains less fatty matter than any other grain, and, as with most of the cereals described, the greater portion of it is found in the husk.

PREPARATION OF THE CORN.—The first operation is the cleaning of the grain.

Cleaning and Winnowing.—In French, American, and English steam mills the machinery for cleaning the grain is generally of three kinds; the first consists of a series of sieves, which remove the foreign materials, stones, shells, &c., and finer impurities, from the grain.

The second apparatus removes the husk of the grain, the runner being elevated so that none of the grain is reduced to powder during the action.

The third separates sand, dust, or any other dirt from the grain by attrition: to effect this a cylinder lined with brushes is made to revolve, and these, by scrubbing the grain against the cylindrical file-like surfaces of the case, effectually detach all the lighter bodies. The light dirt being disintegrated, is afterwards removed completely by a winnowing fan worked by the machinery.

Figs. 1 and 2 are drawings of an apparatus for cleaning, winnowing, and separating different kinds of grain at one process, invented by MM. JEROME BROTHERS, of Amiens, and used in several districts of France. Fig. 1 is a front exterior view, and Fig. 2 a vertical section made through the axis of the apparatus. The different working parts of this machine are so arranged as to occupy little space, and to effect the various operations in a steady and uniform manner, requiring but little motive power. The frame in which the whole machinery is inclosed consists of two cast-iron cases, A. The corn to be cleaned and sifted is first thrown into a hopper, B, from whence it falls into the riddle, C, by which the straws and all other bodies larger than the grain are removed. This riddling-box receives a jerking motion directly from a cam, fixed at the extremity of the horizontal iron shaft, E, which carries the vanes of what may be termed the "thrasher." The riddled corn falls by the inclined sluice, I, towards the lower part of the fixed drum, G, which is formed of rasped sheet iron, having its rough side inwards, and which, at its opposite ends, is closed with a metal grating, H. The horizontal shaft, E, carries two series of arms, *i i*, to which are attached the wooden vanes, J, and these are in like manner furnished with sheet iron rasped on the surface, so that, by the rapid rotation communicated to the axis, they beat the corn against the interior of the drum, and raise it, while being subjected to this process of thrashing, to the upper part, whence it proceeds by the channel, K, towards the end of the machine, into the box, L, closed in front by a cover of wire gauze, through which passes the air that is driven by the vanes. All the dust which is disengaged from the corn passes from the drum through its various little openings into an exterior case, and is then delivered into a kind of trough, N, which constitutes the lower part of this exterior case. The dust is removed, when desired, by a small door of sheet iron. The cleaned corn falls from the box, L, into the riddle, O, in proportion as it is winnowed by the air from the vanes, J, which air escapes by the passage, P.

This riddle or sifter, which has for its object to separate all the small seeds and dwarf grains from the good corn, receives also, like the first riddle, a more or less energetic oscillating movement, by means of the lever, Q, which, at its lower extremity, carries a stud acted on by the cam, R, fixed near the end of the horizontal shaft, E. A spiral spring, S, the tension of which may be regulated at pleasure by the aid of an abutting screw, limits to any required extent the oscillatory movements of the riddle. All the good corn which passes out at the lower end of the riddle is delivered into the inclined sluice, U, from which it may be received into a sack; and all the refuse which has passed through the holes of the sieve descends into the receptacle, V, at the bottom of which is a door for the purpose of removing it when necessary.

Fig. 1.

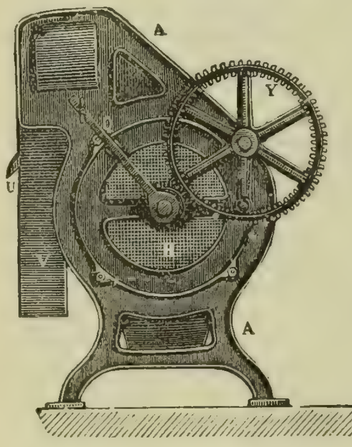
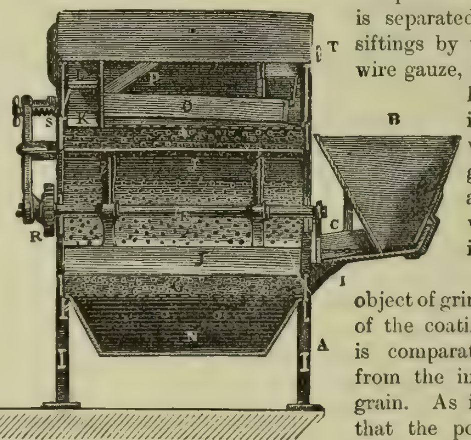


Fig 2.



When this machine is fitted to a mill where it can be driven by a constant force, a fixed cast-iron pulley, connected with the main shaft of the machinery, is mounted at the end of the horizontal shaft, E; and a loose pulley is also provided, to allow of interrupting the movement at pleasure. When, on the contrary, the apparatus is to be driven by hand, a toothed pinion is applied to the shaft, E, and this gears with a large wheel, Y, to which a handle is fitted. The teeth of this wheel are made of wood, but of a particular construction. They are dovetailed into the iron circumference of the wheel, so as that the wood is surrounded with the metal on three sides. In this way each of the teeth is solidly fixed.

The sifting process is effected by a very simple arrangement, which permits of collecting separately grains of different kinds and sizes that have been mixed together; in a word, which performs the part of a "sorter," while at the same time the work of cleaning is accomplished. This arrangement consists in placing within the riddle several pieces of wire gauze of different degrees of fineness, the one over the other, and making these correspond to the different sizes of the several kinds of grain to be collected. One piece of this gauze is fitted in the receptacle for the siftings, V; another is connected with the outside of the machine by the sluice, U. The effect produced by this arrangement is as follows:—The mixed grains of rape and poppy-seed, for example, fall on the upper wire sieve, the poppy-seed passes through and falls on the second, while the rape-seed, being larger than the poppy-seed, travels over the upper sieve and falls out at the end of the riddle into a separate receptacle. The poppy-seed is separated from the refuse siftings by the lower sieve of wire gauze, through which the latter pass and fall into the reservoir, V, while the good grain or corn arrives at the sluice, U, from which it is received into a sack.

Grinding. — The object of grinding is the division of the coating or husk, which is comparatively indigestible, from the interior part of the grain. As it has been shown that the portion nearest the *shell* is richest in nitrogenous substances, it is evident that the more completely the finer parts are separated from the integument, the more nutritious will be the flour. In attempting to gain this point, the miller frequently runs into extremes, either reducing the grain to such a minute state of division that the husk passes through the bolter with the flour, or not grinding the grain fine enough, whereby flakes of the most valuable part are thrown away.

Mills, generally speaking, contain three classes of machinery; that for the actual grinding, the hopper which supplies the grain to the stones, and the bolter and its case, where various sieves produce flour of the requisite fineness. In Germany this set is called a *gänge*. In mills lately constructed, besides the preceding being more complete, various other apparatus are appended.

In noticing the first class of machinery, the millstones claim priority. These are rarely entire, being almost always constructed of several blocks cemented together by gypsum or Portland cement, and surrounded with strong iron bands. Their size varies from 3 to 5, and occasionally 7 feet in diameter. The stone should be so hard that it will not readily become smooth, yet not so hard as to render its dressing or grooving difficult. Blocks hewn out of the Rhenish lavas are preferred in Germany for their hardness and open texture; for, as the stone is abraded, the blisters break, forming a series of cavities bounded by sharp edges, which partially supply the place of artificial grooves. The best mill-stones in this country are made from a very hard silicious rock, known by the name of *Buhr* or *Burr-stone*, and found only, in any quantity, in the vicinity of Paris, and a few other places in France. It is imported into this country as ballast. Its pores are very large, often requiring to be filled with alum and grit, yet, at the same time, it is so durable, that a pair of stones have been known to last in active operation for twenty years.

In cutting them, the surfaces of contact are not left smooth, but are indented to a depth of from a quarter to one-eighth of an inch, in a series of lines diverging from the centre to the circumference. This grooving is called the "dressing." If the stones were without the indentations, the grain would only be crushed, in which state it would clog and adhere to them, thus offering a great obstruction to their rotatory motion. In such a case the portions thrown out, instead of being properly separated from the husk, are found so blended together with it, unless the corn is completely dried, that it is impossible to detach, economically, the valuable parts of the grain. Even if kiln-dried grain was used, the operation could not be conducted with smooth-surfaced stones, on account of the heat which close friction occasions in the flour; besides this, a glaze or polish would be given to it, by which its quality would be impaired.

There are various methods of grooving the stones. Fig. 3 represents the American plan of dressing, which is considered the best. The grooves in the top stone, or "runner," are so adapted to the lower or "bedstone," that, when motion is communicated to the former, an action takes place between the identations of both stones, similar to that of shears or scissors. In dressing, the furrows are never made perpendicularly at both sides, but at one side the groove is cut vertically, and the opposite side diverges from this straight line at an angle of about 45°. Both stones are grooved in the same manner and direction, but when the runner is afterwards placed in its working position, the course of the stones, as also that of the channels, is reversed, and both the edges meeting in opposition, cut the intermediate grain into fragments; these, in being swept over the "landings," or smooth spaces of the mill-stones, are ground fine.

Fig. 3.

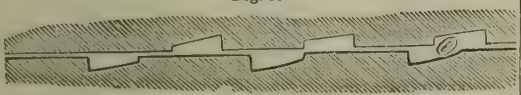
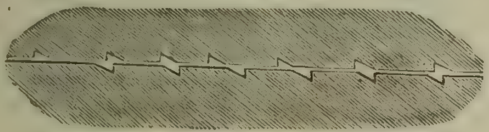


Fig. 4.



Sometimes, instead of the channels being curvilinear, as in the preceding woodcut, they are straight, as in the annexed sketch of the stones of a French power mill—Fig. 4. A similar dressing is practised in this country, but the number of long or "master furrows" is generally eight, and the shorter or auxiliary ones twenty-four.

Fig. 5.

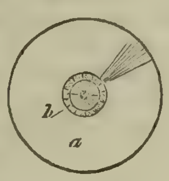
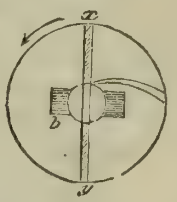


Fig. 6.



In ordinary mills each stone is, for the most part, dressed differently (Figs. 5 and 6), the runner, *b*, having spiral channels from the centre to the circumference, while those of the bedstone, *a*, are radii. A large diametrical canal, *x y*, is cut in the runner for admitting air. The central circles, *h b*, in these engravings show the spaces through which the spindles pass, the arrow shows the direction in which the runner travels. Figs. 7 and 8 show the arrangement of the furrows.

Fig. 7.

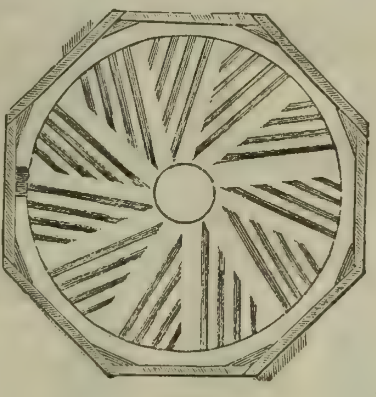
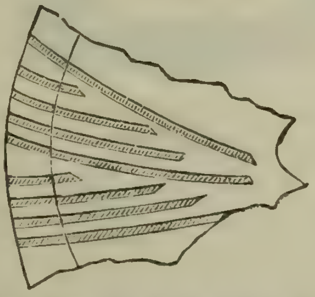


Fig. 8.



When the stones are again dressed, the furrows are reversed, the spiral ones being cut into the bedstone, and the radii into the runner.

The use of the hopper and bolter will be explained when reference is made to the general construction and employment of each part of the mill.

Mills are often differently made, but, excepting the motive power, the same principles are referrible to them all. Wind, water, or steam is used, the choice being dependent, to a great extent, upon the position of the mill-house.

Fig. 9 is a section of an ordinary mill, moved by a large water-wheel, not shown in the engraving.

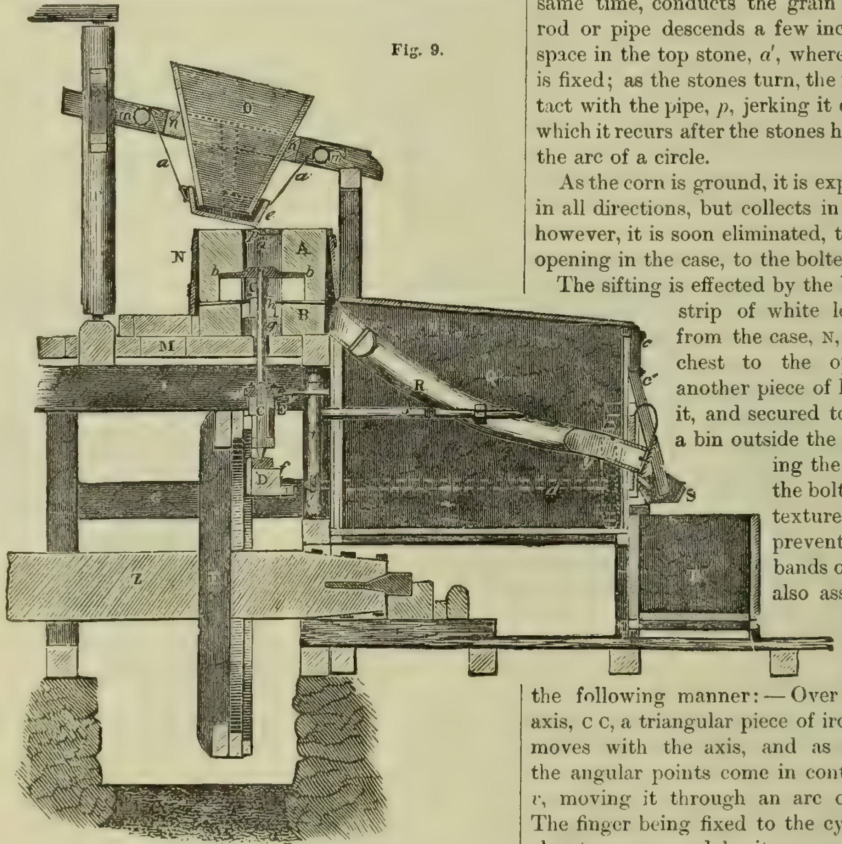


Fig. 9.

The shaft from the water-wheel is generally a large beam of wood, represented in the cut by Z; upon this the second or principal wheel, F, is constructed, the cogs of which act upon the fly, E, of the spindle, C, which is an iron bar forming the axis of the stones; its lower end is conical, and rests upon a bed of steel, *f*, which is supported by the beam, D, fixed upon other cross-beams, G and L, forming a kind of leverage, whereby the beam, D, and spindle, C, are depressed or elevated as required. The stones which grind the corn are A and B, the latter being the bedstone, in the middle of which, as at *g*, the iron bar, C, passes through a tightly-fitted packing-box, *h*, to the runner in which it is fastened, by fixing in the circular space cut away—about 6 or 8 inches in diameter—an iron bar, *b b*, having a rectangular hole in the centre, into which the end of the axis, C, exactly fits. This apparatus is called the "ryne."

A case, N, envelopes both stones, to protect them from dirt, and to prevent the flour from being scattered about by the centrifugal force of the runner. Over that part of the machinery already described a prismoidal-shaped hopper, O, is supported upon a frame, *n n*; into this box the grain is emptied, whence it is supplied to the stones by the motive power of the mill. The bottom of the hopper is received into a movable box, *e*, called a *shoe*, which is suspended by the cords, *a a*, passing round the fluted rollers, *m m*, in such a manner that the orifice in the bottom is partially closed, allowing no more grain to pass from it than is necessary to supply the stones. The corn is not let in at one place, but is made to enter on each side of the ryne by a shaking motion communicated to the shoe by the iron pipe, *p*, which, at the same time, conducts the grain to the runner. The rod or pipe descends a few inches into the circular space in the top stone, *a'*, where a serrated iron ring is fixed; as the stones turn, the notches come in contact with the pipe, *p*, jerking it out of its position, to which it recurs after the stones have revolved through the arc of a circle.

As the corn is ground, it is expelled from the stones in all directions, but collects in the case, N, whence, however, it is soon eliminated, through a rectangular opening in the case, to the bolter in the flour-box, Q.

The sifting is effected by the bag, R, attached by a strip of white leather to the outlet from the case, N, passing through the chest to the opposite end, where another piece of leather is fastened to it, and secured to a pipe opening into a bin outside the flour-box for receiving the bran. The cloth of the bolter is of such a fibrous texture and stiffness as to prevent it collapsing; the bands of leather at each end also assisting in keeping it in proper form. A continual motion is given to this bag in the following manner:—Over the fly, E, of the axis, C C, a triangular piece of iron, *w*, is fixed, which moves with the axis, and as this piece revolves, the angular points come in contact with the finger, *v*, moving it through an arc of from 40° to 45°. The finger being fixed to the cylinder, *t*, causes this also to move, and by its means the rod, *s*, and the bag, R, with which it is connected, are tremulously agitated. In this manner the finer parts of the flour are sifted through the bolter-cloth; while the coarser flour and bran pass off to the bin, T, or are received in the sieve, S, where the coarser parts of the flour are completely removed. A similar oscillating motion is given to the sieve by the wooden spring, *c c'*, and the spindle, Z, through which the conducting-rod, *d*, passes. The coarser parts are often returned to undergo a second grinding and sifting.

An ingenious machine for dividing the flour from the bran, and which is very generally used, separates several kinds, according to their state of division, at one operation. It is termed the "dressing machine," and consists of long, hollow cylinders of wire-gauze, of various degrees of fineness, according to the qualities of flour to be produced, protected on the outside by a framework of longitudinal and circular slips of wood, put at regular distances from each other, the whole being fixed in an inclined position. In the interior a set of brushes revolves, rubbing against the wires, and clearing the meshes from adhering particles.

The entire machine is inclosed in a box, which prevents the escape of floury particles in the form of dust. The cylinders of wire-gauze are so fitted in as to be readily replaceable by others, of any requisite size, to suit the fineness of the flour to be separated.

After some time the meshes of the cylinders get filled with adhering particles of flour, and the brushes also lose much of their effect from the inclination of the bristles, occasioned by being worked in one direction; consequently, the dressing is very imperfectly accomplished. The first difficulty is overcome by means of a strong brush rubbed exteriorly against the wires from time to time; the adhering substance is by this means completely removed. The second fault is obviated by having the brushes so arranged that they can be made to move in either direction, by which they last a longer time and work much more effectually.

Fig. 10 represents the whole mill. E E is the masonry for supporting the driving gear of the machinery; F, the steam-engine; K K is the spur fly-wheel of the engine working into the pinion, L, The main horizontal shaft of the mill is represented by M M, and the level mortise wheels and pinions for driving the stones are seen at N N N; P P P are the millstone cases. There is a passage conducting the grain from the elevator to Y Y, the "creeper," by which it is distributed into Z Z Z, the garners for feeding the stones. A′ A′ A′ are feeding pipes made of tin plate; B′ B′ B′, pipes by which the flour is withdrawn from the stone cases into Y′ Y′ Y′, the second creeper-box, which conducts it to the second elevator; C′ C′ is the shaft which works the dressing machine by the bevel wheels, *a* and *b*.

Fig. 10.

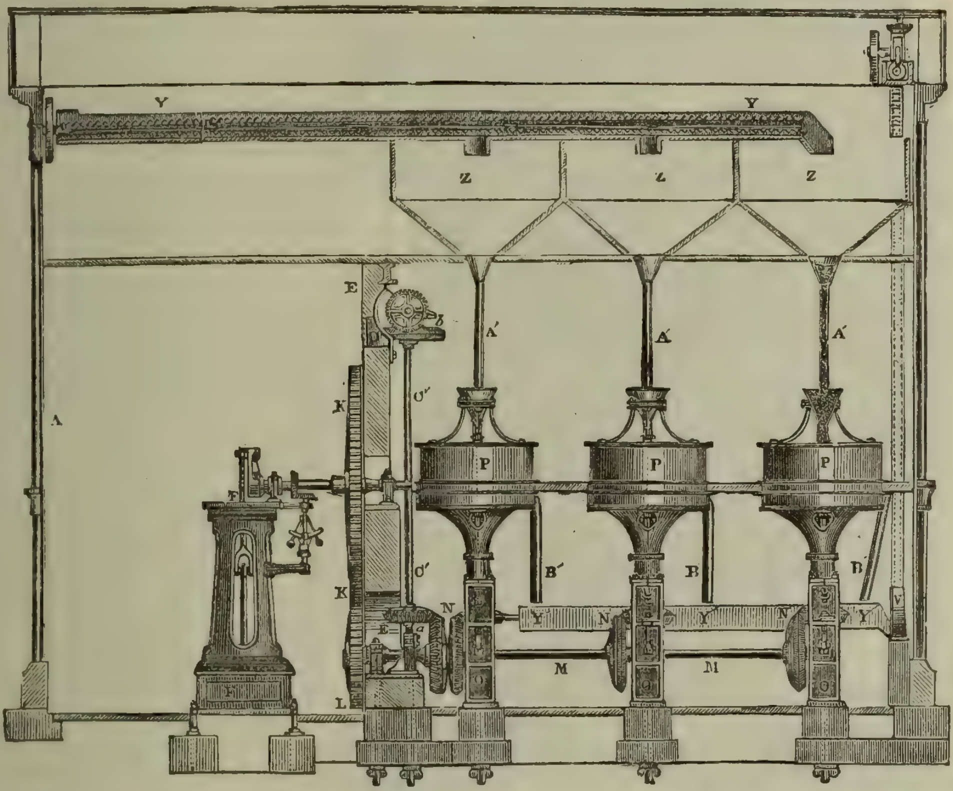
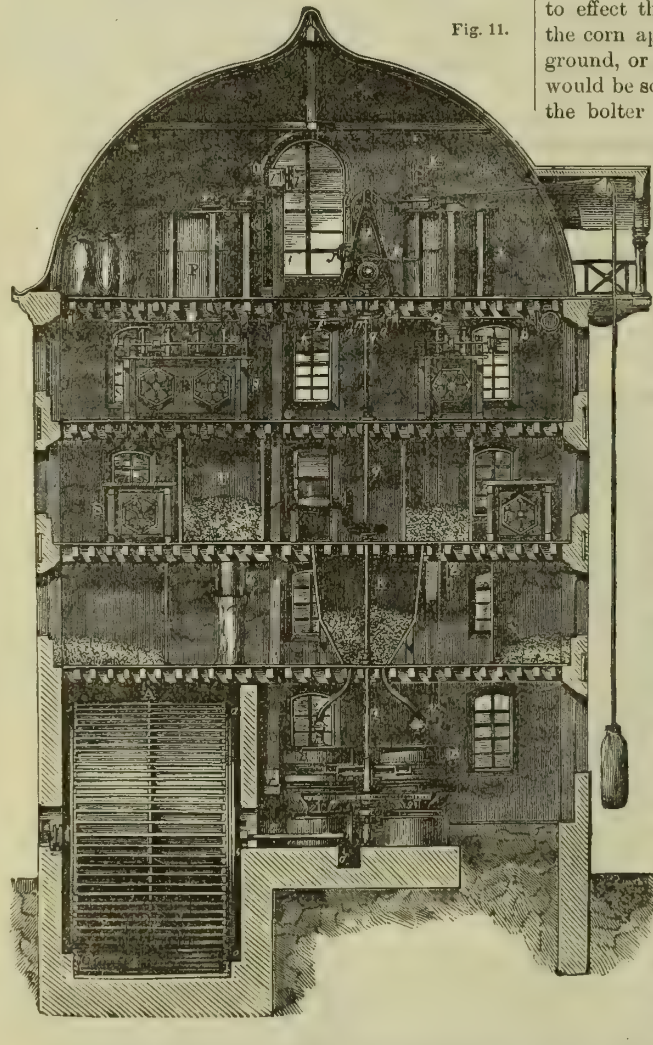


Fig. 11 is a sectional view of the interior arrangement of a French flour mill. The motive power is a water-wheel, A, and by means of a spur-wheel, *c*, appended to the axis and pinions, *b b*, this is made to move the stones, B B. Motion is likewise communicated to the cleansing machine, P, the bolters, R R, &c., by an upright shaft, *q′ q′ q′*. The corn is cleansed by a winnowing machine, L, before it descends to the hopper, K, from which the stones are supplied. An endless chain of buckets, O O O, raises the flour from the stones to the bolter, *p*, whence, after undergoing a purifying process, it descends to the several other machines, R R R, by which the various qualities of flour are separated and collected in sacks. The details of the arrangement are too numerous to be fully stated, but the figure above given will be intelligible to every miller.

By the common methods the grain which is ground at one time must be passed through the stones repeatedly, their relative position being altered each time, according to the degree of fineness required. The stones, by continued use, become so much abraded that they would no longer touch the grain if the miller did not, from time to time, regulate their distance by a screw provided for the purpose.

Fig. 11.



During the first two or three courses of the corn between the stones the runner is so raised that the grain is only coarsely broken, and this is repeatedly passed through the grinding and dressing apparatus till no more flour is reduced; the residue is bran.

Fine flour of various qualities is obtained from that portion of the grain which flies off as dust from the bolter, and the other parts remaining, already deprived of the bran, are designated by different names, according to their appearance and degree of fineness. In some of the London mills no less than seven different products are obtained, the relative quantities of which are the following:—

Fine flour,..............	5 bushels	3 pecks.
Seconds,..............	0 "	2 "
Fine middlings,..........	0 "	1 "
Coarse middlings,........	0 "	0·5 "
Bran,..................	3 "	0 "
Twenty-penny,..........	3 "	0 "
Pollard,................	2 "	0 "
	14 "	2·5 "

The grain is usually moistened before grinding, to effect the complete separation of the husk. As the corn appears in the market, it is too dry to be ground, or at least, if ground in this state, the husk would be so finely divided that it would pass through the bolter with the fine flour, and communicate a brownish colour, which would be very objectionable. To prevent this the grain is cast into a tank of water, the lighter impurities as they rise to the top being skimmed off. After draining the excess of water, another portion of dry grain is added to that which was moistened, and after the mixture has been left to soak for some time, it is submitted to the mill. Many millers merely sprinkle the grain with the water.

The flour, as it comes from the stones, is hot, on account of the great friction to which it is subjected, and if allowed to remain at the acquired temperature *en masse*, it would ultimately become acid, particularly if the grain contained much moisture.

In well-regulated mills this source of injury is neutralized by immediately conducting the ground material by means of an elevator to a spacious floor in the upper part of the building, where it is spread out to cool. This operation is the more needful when the grain is so dry that the husk cannot possibly be detached from the flour in the grinding, unless it be previously moistened.

In consequence of the moistening process, the finest quality of flour imported from America is often found agglutinated into hard musty lumps. Mitscherlich and Krocker, who examined this subject, show that wheat in which sugar was proved to be absent before sending it to the mill, yielded after being ground as much as 4 per cent.; this transformation of the starch into sugar could not be produced otherwise than through the internal action of the gluten, aided by air and superabundant moisture. When once the action sets in, it quickly passes through the whole heap, if not speedily checked either by cooling or drying the floor. The decomposed starch or sugar, when the mass is left to cool gradually in large heaps, soon enters upon the alcoholic, and sometimes even the acetous fermentation. This action always takes place in the middle of the heap first, and proceeds towards the surface. The affected flour has a gritty feel, not unlike that of gypsum, and, of course, makes very unwholesome bread.

Flour containing only its natural portion of moisture is the best for stock and exportation. Bergs kept various samples of flour, and found that the second and third qualities, which contained most gluten, were completely spoiled after keeping only nine months, during which no want of care could be alleged as the cause, as the casks were placed in a cool, airy, and dry warehouse.

Many English millers are much opposed to moistening the grain previous to grinding it, and even dry damp grain upon a kiln to deprive it of an accidentally acquired humidity; the flour which they obtain, though inferior in colour to other varieties, is better adapted for storing and exportation than any other. The American flour is decidedly the whitest brought into the market; this must be owing to their more perfect sifting machinery, and cannot be from the better quality of their grain, as it is universally allowed that English wheat is seldom or never surpassed. The Americans also cool their flour very rapidly by means of special machinery, while the English miller leaves it to cool in the sack.

The best way of securing a flour of the whiteness of the American article, and possessing at the same time the durability of the English, would be to grind the grain slightly moistened (as is the custom with the American millers), and afterwards to dry the flour in properly constructed chambers; the excess of moisture would in this way be expelled, and the husk or bran would be more completely detached from the flour. This method has been tried on flour for shipment with very favourable results.

On the whole, English millers obtain a larger bulk of flour than the Americans. Bran, as it comes from English mills, only slightly whitens a black cloth, whereas American bran retains considerable portions of the matter of the grain attached to it.

The following are data given by Knapp, showing the proportionate results obtained from the old and new mills; and as this chemist states them to be the mean of six experiments, they may be looked upon as a fair comparison of their merits.

From 100 lbs. of maize were produced in an old mill—

Fine flour,	55	pounds.
Middle flour,	18	"
Black flour,	9	"
Bran,	18	"
	100	

And from the same weight of barley the proportions were—

Fine flour,	40	pounds.
Coarse flour,	20	"
Middle flour,	10	"
Black flour,	5	"
Bran and loss,	25	"
	100	

In a new mill at St. Maur, near Paris, there were obtained from every 100 parts of grain—

72	of flour, first quality,
3	of flour, second quality,
3	of flour, third quality,
7	of coarse bran,
10	of fine bran,
3	of black bran meal,
1	separated by sieves,
1	loss.
100	

Dr. Hassall gives the following table as the yield of a quarter of wheat—weighing 504 pounds—when ground:—

	Pounds.
Flour,	392
Biscuit, or fine middlings,	10
Toppings. or specks,	8
Best pollard, Turkey pollard, or twenty,	15
Fine pollard,	18
Bran and coarse pollard,	50
Loss sustained by waste in grinding, &c.,	11
	504

Bread Making.—If flour is worked up with water, and dried either spontaneously or at a very low heat, a substance is obtained which binds together with no great degree of firmness; the starch and other matters remain in such a mass unaltered; it is insipid and indigestible. But if the mass be heated throughout for some time at a temperature of 212° Fahr. (100° C.) a change occurs; the starch is rendered soluble, and the whole body becomes firm, dense, and compact. Such was in ancient times the bread making process universally practised; even still, in many parts of the world, this method of baking is continued, as in the North of India and Afghanistan: the Jews also make their Pascal or unleavened bread in this way; and in preparing sea-biscuit this method continues, with only slight modifications, to be generally adopted.

Bread prepared in this manner is merely the dough dried in a peculiar way, with the formation of an outward crust, and the thinner the cakes are made the more easily is this effected. The density of such bread is much greater than that of fermented bread, and in consequence of all moisture being expelled, and the constituents of the flour being only very slightly different from their original composition, it is difficult to masticate; it keeps, however, a much longer time than any other kind, and on this account is admirably adapted for sea stores.

A most necessary quality in bread is, that it should be furnished with a thin crust, and have sufficient porosity to present a large surface to the action of the gastric juice; and to insure these qualities various means are adopted. Fatty and oleaginous matters are used to distend the plastic mass, which they effect as in the formation of pie-crust.

Leaven, another of the bodies used to give bread a great degree of porosity, is a portion of the ordinary dough left in a warm situation till fermentation sets in; if left too long under this influence, however, it becomes first sour and then putrid. The use of leaven in baking is to induce the same fermentative action in the fresh dough which is going on in itself;

but it should be employed with the greatest caution, for if the acid transformation has commenced in the leaven, it will communicate a disagreeable taste to the bread.

Yeast is now almost universally used in place of leaven, and has considerable advantages over it, since it confers porosity in a high degree, without generating any disadvantageous property in the loaf.

The principal materials requisite for obtaining good bread are flour or meal, yeast or leaven, and water, with a suitable quantity of salt; various other matters may be added to confer greater whiteness and richness on the loaf.

Fermentation.—Panary fermentation, induced by yeast or leaven, is the same as that which takes place in the formation of alcohol, though the action is more limited. It has been shown that sugar is not a constituent of grain, more especially of wheat; though, when the latter is exposed to moisture, this substance is formed in considerable quantities. When the flour is mixed with a proportion of water sufficient to form the dough, the production of sugar becomes more brisk, for the gluten of the flour induces its formation, and the ferment, whether it be leaven or yeast, effects the conversion of this sugar into alcohol and carbonic acid gas to a greater or less degree. All the sugar which the gluten of the flour would be available in producing is not, however, formed in the dough; but the amount is proportionate to the time the flour is left in contact with the water and ferment, before its introduction into the oven.

The formation of a lump of dough by the use of a ferment and water will readily demonstrate that not only is a considerable surface exposed to the air, but a volume is also enveloped in the mass; and, as has been shown under Acetic Acid, alcohol in contact with air or oxygen, at a slightly elevated temperature, readily passes into vinegar; so, in this case, the decomposition of the spirit follows, if fermentation be prolonged beyond the necessary period.

The retention of the carbonic acid and alcohol is the cause of that sponginess which is so desirable in bread; but it will be seen that some portions of the valuable constituents of the flour are destroyed to give existence to them, and so far as the vesicular structure of the dough is concerned, their action is merely mechanical.

Various compounds setting free carbonic acid have been tried as substitutes for yeast, but their use is always attended with indifferent success. The reason is evident. When such substances are decomposed to give the carbonic acid, the action takes place so rapidly that the baker has not time to work his dough as usual, and still retain the gas; and even during the short time which he requires to form the loaf, a considerable portion of the elastic fluid is evolved to his loss. It appears, also, that the loaves made by such treatment are full of large cavities, with interposed walls of doughy consistence, unlike bread fermented with yeast, which is so regularly cellular through its entire extent, arising from the carbonic acid and spirit being generated in all parts of the mass of dough.

It is a remarkable fact, that a little soap-suds added to the dough arrests fermentation; its action depends upon the absorption of the carbonic acid by the alkali of the soap, forming a carbonate, and the fatty acid of the soap is liberated: both these are anti-ferments, but besides their arresting the fermentation, the bread is rendered dense by the absorption of the carbonic acid already formed. Yeast possesses a very disagreeable bitter taste before it is mixed with the flour, but when the loaf is baked no such taste can be detected.

Fownes has shown that flour and water mixed, and left at the normal temperature of a moderately warm room, arrives at the usual state necessary to induce fermentation in malt wort, only after a period of six or eight days; during this time the mixture contracts a bad odour and an acid reaction. The conclusion from this fact is, that dough should be left to the action of the ferment only so long as is necessary to generate sufficient carbonic acid gas to give the loaf its proper size.

Greater difficulties are encountered with leaven than when yeast is used; for, as has already been mentioned, leaven is merely a portion of the dough in a state of fermentation, reserved for the next operation, to induce similar action in fresh portions of flour to that which it undergoes itself, and this it effects in a manner similar to that of fermenting worts with a fresh infusion of malt, as fermenting grape juice reacts upon a fresh extract of the fruit, or as yeast serves the same purpose.

During the action of the leaven other compounds, such as lactic acid and complex nitrogenous substances, arising from the decomposition of the plastic bodies of the flour, are formed; and when the leaven is added to the dough in this stage of decomposition, it gives rise to like compounds, and the result is that such bread speedily turns rancid, and consequently is unfit for use.

Persons with weak digestive organs are unable to use bread made in this way—"black bread."

The fermentation of dough, if allowed to proceed, ends in putrefactive decomposition; and if the fermenting dough has entered into this phase, it tends to induce the same change in the fresh paste, without any intermediate modifications of the fermentation being observed. The state of the leaven must therefore be carefully noticed before using it.

Yeast is easily retained in good condition by mixture with sugar, but leaven demands more care. In Germany, where leaven is used to a large extent, the baker mixes a quantity of it with a portion of the flour and water intended for the next baking; as soon as the fermentation has raised this first addition, a larger portion of the flour is added, in the same way as before, the whole left again to ferment, and so on each time, till about one-half of the flour is in a state of fermentation. This procedure is called by the Germans *Anfrischen*, and its object is to supply sugar so as to maintain the vinous fermentation. The quantity of ferment or leaven required when used thus is very small in comparison to what would be necessary if the whole of the flour was added at once; and the retention by the dough of the alcohol and carbonic acid developed throughout the fermentation produces a uniformly raised loaf.

Various sorts of bread are obtained from the several kinds of flour. Wheaten bread, or "firsts," is made of the finest flour; household bread, or "seconds," is made of somewhat coarser flour; brown bread, or "thirds," is made from an admixture of two or more kinds of flour remaining after the firsts and seconds flour have been taken away; and "composition bread" is made of ground but undressed wheat.

The yield of bread is generally about 90 quartern loaves per sack of 280 lbs. of flour. If the flour, however, be of the best quality, more water is retained, and a greater weight of bread results. When the dough is made of the proper consistency, the usual loss by baking amounts to about one-tenth of the weight of the mass of dough, or one ounce and a half to the pound.

BAKING APPARATUS.—The ordinary apparatus and other requisite furniture for common purposes, are comprised in the following:—On one side of the room a large dresser is erected, and over it a range of shelves. The kneading-trough occupies the opposite side of the room; it is generally from 6 to 9 feet in length, 3 in height, about 2½ in breadth at the top, and tapering to the bottom, where it measures only about a foot and a half. A sliding or sluice-board is furnished in the interior, and a lid covers the whole. At one end of the room is a boiler, holding from 15 to 30 gallons of water, and at the other end the oven.

The other utensils of the bakehouse are the "seasoning tun;" the "seasoning sieve," made of hair, tinned sheet-iron pierced with holes, or perforated zinc; wire sieves, for sifting the flour; a salt bin; yeast tub; a bucket; a spade or shovel; a bowl; scales and weights; and a large dough knife; a scraper, for cleaning the dough off the trough and moulding board; four or five short shovels of various sizes, attached to long handles, and called "peels," which are used to put the loaves in, and also to take them from, the oven; tin or iron plates; cloths for covering the dough and bread; a "scuttle" or "swabber" for cleaning the oven preparatory to setting in a batch of bread; supports, made of rectangular pieces of beech, fixed round the sides of the oven for the purpose of keeping the loaves in their places; the "rooker," a tool in the form of the letter L, for the purpose of drawing out the ashes from the oven; a hoe, used for a similar purpose; and a rasp for detaching any burned parts from the baked loaf.

The baker first of all starts his ferment with potatoes. To do this he boils, peels, and mashes 5 to 6 lbs. of potatoes for each sack of flour used, and adds to these 1½ gallons of water, 2 to 3 lbs. of flour, and 1 quart of yeast. The whole is then stirred till it becomes a smooth paste. Fermentation speedily sets in, and in about three hours will have come to a head, when the dough may be made.

To do this the baker takes about 2 gallons of water at a temperature varying from 70° to 100° Fahr. (21°·1 to 37°·7 C.), and adds the yeast prepared as above, and enough flour to make a stiff dough. The amount of water employed varies considerably with the quality of the flour, being from 40 to 60 or 70 per cent. of the flour. As a rule, the bakers use equal weights of water and flour.

Good flour always requires more water than inferior, to bring it to the consistence necessary for the retention of the volatile compounds which will be subsequently developed; the starch and gluten in good flour being in a more minute state of division, and therefore more retentive of water.

Having mixed the water, yeast, and flour, as above, proportionably, to give the mixture a thick ropy consistence, the mass is permitted to rest for some time; a proper quantity of salt is next added, and the whole covered up in a small kneading trough in a warm situation. This mass is called the "sponge," and the placing of it in a warm situation is termed "setting the sponge," being in effect the inducement of the vinous fermentation in the sugar of the flour, signs of which appear in about an hour afterwards, by the mass becoming inflated from carbonic acid gas arising out of the decomposition of the sugar into alcohol. If the sponge be too thin the bubbles of carbonic acid rise quickly to the surface, break, and are lost, leaving it almost in its original state; but when it is of moderate consistence, the tenaciousness of the mass retards the evolution of the carbonic acid till it accumulates in large quantities, which distend the sponge until it can no longer retain it. The escape of the gas causes the dough to collapse; and as a further quantity of gas is produced by the progressing action of the ferment, the dough rises as before, till it acquires twice its original bulk, when it again falls. Were this operation of the sponge suffered to continue, it would last for a considerable time; but in that case much of the valuable constituents of the flour would be destroyed, and the prolonged action would convert the alcohol into acetic acid and spoil the bread.

After the first rising, if the baker judges that fermentation has pervaded the whole mass, the baker "breaks the sponge" by adding the remaining quantity of flour, water, and salt (in the proportion of 2½ to 3¾ lbs. per sack—new flour requires the latter quantity to make the dough to "bind"), and incorporates the whole material thoroughly by "kneading." But if he thinks that the operation is partial, he delays adding the second part of the flour till the second rising; this he calls "taking a second fall."

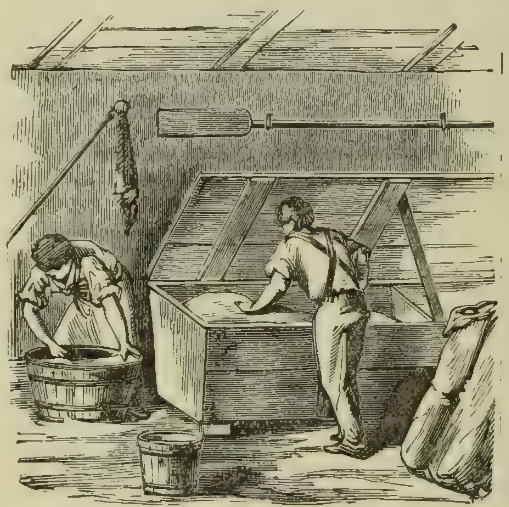
The kneading is continued till the fermenting sponge becomes completely incorporated with the flour recently added; for without this precaution the cellular texture of the loaf would not be attained, and the fresh flour would be left in doughy concretions in the mass. Hence the kneading forms a material part of the baker's work, and should always be well executed, as no loaf is properly made unless it has been thoroughly wrought up. By this mechanical operation, the glutinous parts of the flour are rendered so elastic that the mass of dough which is made is capable of expanding to twice or three times its volume without cracking. The criterion by which the baker judges when the dough is properly blended is by indenting it, and if it does not adhere to the hand on its withdrawal, he considers that the dough is properly worked.

Fig. 12 represents the kneading trough.

After the first operation, the dough is covered up with a flannel cloth and left at rest for a few hours, during which time it is in active fermentation and swells considerably. A second kneading is then given, with the view of equalizing the carbonic acid formed in the mass during the time the dough remained at rest, and preventing portions of the bread from being "sad;" it is, therefore, less laborious than the other kneading.

The dough prepared in this way is then weighed out into lumps of the requisite size; these are next shaped into loaves, or put into tins, as the case may be, and set aside in a warm place till they have acquired about twice their bulk, partly from the generation of fresh carbonic acid, and partly from the expansion of that previously formed. The oven being prepared, the loaves, properly shaped and weighed, are introduced and allowed to remain till baked, after which they are drawn out with the peels, being now no less than double the size they were before baking.

Fig. 12.



It is absolutely necessary that the proper volume of carbonic acid should be generated in the dough before it is put into the oven, as the strong heat immediately arrests further fermentation, and the swelling of the loaf arises from the expansion of the bubbles already formed throughout the mass, which gives to it the light porous texture peculiar to good bread. Each of these cellular spaces is bound by a kind of integument, and the whole are so arranged that they form a succession of layers one above the other, and at right angles to the crust. When the loaf consists of an aggregation of the layers it is called by the baker "piled bread." Dr. Colquhoun contrasts the virtue of piled bread with the unpiled by noting that, if the former be pressed in the hand, it will crumble, and if thrown into hot water it will intumesce, disintegrate, and admit of being easily diffused; whereas the unpiled bread, when treated similarly, yields a solid cohesive body, and hot water reacts upon it no further than to soften it into a permanently tough mass.

The oven, previous to the moulding of the loaves, is thoroughly cleaned out with the swab, and the "upsets" or supports chalked, to prevent the loaves adhering to them. The various kinds of loaves are placed in the oven in connection as closely as possible, but the cottage loaves, rasps, &c., must be left some short distance apart, that they may be entirely crusted. Much manual skill is requisite in introducing the bread into the oven; when this is accomplished the whole is retained in its place by a set-up placed in front, the door is next closed, and left so from an hour and a half to three hours, according to the size of the loaves, excepting when it is occasionally opened to view the progress of the baking.

Many bakers use 12 lbs. or more of potatoes to 2 quarts of brewer's yeast, and this quantity is added to every sack of 240 lbs. of flour.

The yeast used by bakers is obtained from the ale breweries. Porter yeast will not answer, as it communicates a disagreeable taste to the loaf. Ale yeast is the best and strongest, and is most extensively used in bread-making. Small-beer yeast is said to be weak and rapid in its effects; it is sometimes used in making rolls. Yeast is of a fawn or light-brown colour, and of a frothy consistence; when newly made it is in brisk action, and bubbles of gas escape from it.

"German barm" is a form of yeast which is much used. It is a paste-like substance, and is sometimes called "dried yeast," and consists of sporules only, with but little adherent moisture and no gas. It is merely yeast precipitated from a fermenting liquid, filtered off, and dried at a proper temperature. The following is the mode of preparing it:—Crushed rye is mashed with a certain quantity of barley malt, and the wort cooled to the proper temperature. Half a pound of carbonate of soda and 6 ounces of sulphuric acid, diluted with their weight of water, are proportioned to every 100 lbs. of the crushed grain employed and mixed with the wort, and fermentation induced by the addition of yeast. From the strongly-fermenting liquid the yeast is skimmed off and strained through a hair sieve into cold water, into which it is allowed to settle. It is afterwards washed with one or two waters, and finally pressed in cloth bags till it has the consistence of dough. Its smell is pleasant and fruity, and it will keep in a cool place for two or three weeks. After this it passes into a putrefying decomposition, acquires the odour of decaying cheese, and, like it, possesses the property of changing sugar into lactic acid, instead of into alcohol as before. 100 lbs. of crushed grain will yield 6 to 8 lbs. of the pressed yeast. It is made in large quantities at Rotterdam, and is imported to this country through Hull.

The utmost care is necessary to be observed in its preparation, as it is very readily spoiled; its vitality is destroyed even by slight mechanical injuries, by too high or too low a temperature, and also by chemical reagents. It is put up in Germany in hempen bags, each containing about half a hundredweight; when exported in casks, it has been known to burst them from evolution of carbonic acid. It should be carefully handled, as a slight concussion with another body injures it; even when packed, it is equally liable to be spoiled, as if the bag, in being removed, falls, so as to receive a shock, it is "killed," and scarcely any of its valuable properties as a ferment remain. Hassall states that yeast which has been thus injured darkens in colour (somewhat like the change which an apple or pear undergoes when it putrefies), and, from being crumbly, becomes soft and glutinous, adheres to the fingers like flour-paste, and sometimes emits a fetid, disagreeable odour.

The injured and uninjured German yeast submitted to a microscopic examination, exhibit no difference in their appearance.

"Patent yeast" is an infusion of malt and hops, the latter being intended to diminish the propensity of the solution to acidify. It is a thin aqueous liquid, through which numerous sporules of the yeast plant are disseminated. Many bakers, in preparing patent yeast, likewise add either common yeast or German barm, with an infusion of flour or potatoes, their object being to make the product more effectual, as these substances supply, in greater abundance, the nourishment of the yeast cells; and contain more material for the generation of carbonic acid.

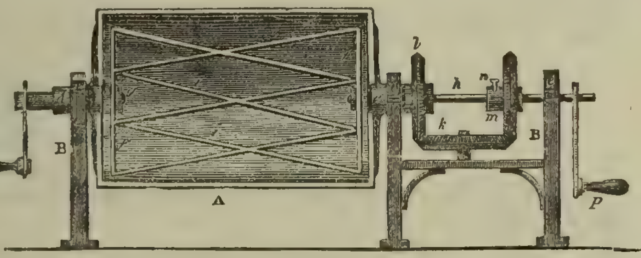
An improvement in bread-making which has been effected of late, is in the kneading of the dough. In extensive bakeries, the trouble of mixing the flour, yeast, and other ingredients, is so great that manual labour could not accomplish it; hence machines have been constructed to serve the same purpose.

There are a great variety of such contrivances, but that of Clayton may be taken as typical. In point of fact any "pug-mill," horizontally arranged, would serve the purpose equally well. Clayton's consists of a rotatory drum or barrel, mounted on gearing, with a hollow axle, and an interior frame of cast iron caused to revolve by a solid axle, which passes through the hollow one. The revolving drum and frame are made to turn in contrary directions, so that the dough is turned over at each time the wheel revolves, and the knives, or diagonal cutters, which are fixed in the frame, tear the mass asunder, and again reunite it till the whole of the ingredients are completely incorporated.

Fig. 13 is an elevated section of the apparatus. A is the barrel or drum into which the several ingredients for the formation of the dough are put; it is mounted on the framework, B B; *c d* are the hollow axles which turn on suitable bearings at *e e*; *f f* is the revolving frame which is placed in the interior of the barrel, A, and mounted on the solid axles, *g h*. The ends of the interior revolving frame are braced together by the parallel slanting spars, *i i i*, which act with great effect in blending the dough, as the case is put in motion. Either the barrel may be made to revolve without the frame, or the frame can be put in motion, leaving the barrel stationary; or, if necessary, action can be communicated to both. The gear work and winches, at each end of the machine, are the means by which the operation is performed. When it is requisite to put the barrel and interior cylinder in motion in opposite directions, the hollow cylinder of the wheel, *m*, is screwed tightly to the axle, *h*, of the interior revolving machine, by the screw, *n*, and by turning the winch, *o*, it will be found that both these motions will be given to the machine.

The interior cylinder, *f f*, may be worked by unscrewing *n*, and turning the winch as before; for the axle, *h*, does not communicate with the wheel, *m*, except by the screw, *n*. Again, if the rotatory action of the barrel be wanted, leaving the other stationary, it may be obtained by turning the handle, *p*, which, however, gives motion to the wheels at the opposite end, but this has no power to act upon the inner cylinder, if the screw, *n*, be disconnected.

Fig. 13.



A kneading machine used in some of the French bakehouses is represented in Figs. 14 and 15, the first being a longitudinal section, the line of division passing through the axis, and the other a front elevation. P P, the frame of the machine, is made of wood, and divided into three compartments for the reception of the dough. The wooden bars, *o o o*, are placed in the interior of the chambers, so as to divide the dough whenever the cylinder revolves. One portion, D, may be opened and laid over upon the other by means of a hinge and movable joint when the dough and flour are introduced. Of A, B, and C, the three divisions of the machine, two—B and C—are reserved for making the dough, the other being used in preparing the sponge. *a* is a pulley which receives its motion from the engine, and transmits it to the cylinder by the pinion, *b*, and the spur-wheel, *c*; *d* is the fly-wheel to regulate the motion of the machinery; *g* is a break to act upon the fly, *d*, by means of a lever, *h*; and *i*, the pillar of the fly-wheel.

The compartments of the machine are furnished at pleasure with cross-bars, which serve to draw out the dough.

When operations are continuous, the sponge is constantly being prepared from a mixture of—

275	pounds of ordinary leaven,
148	pounds of flour, and
76	pounds of water, making a total of
499	pounds.

When the kneader has been at work for seven minutes the cylinder is opened, and after verifying the state of the leaven—adding water if it be too stiff, or flour if the reverse be the case—the lid is once more closed, and the machine again put in motion. In ten minutes afterwards the kneading is completed. As much sponge is obtained from the two kneading compartments, containing about 500 lbs. of dough, as keeps two ovens at work alternately.

Fig. 14.

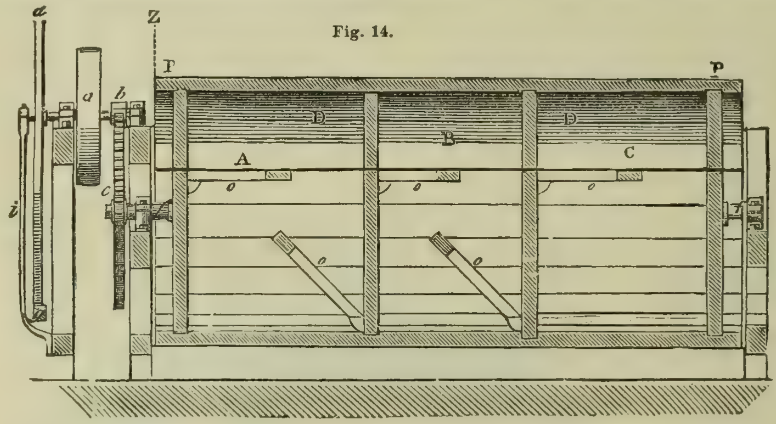
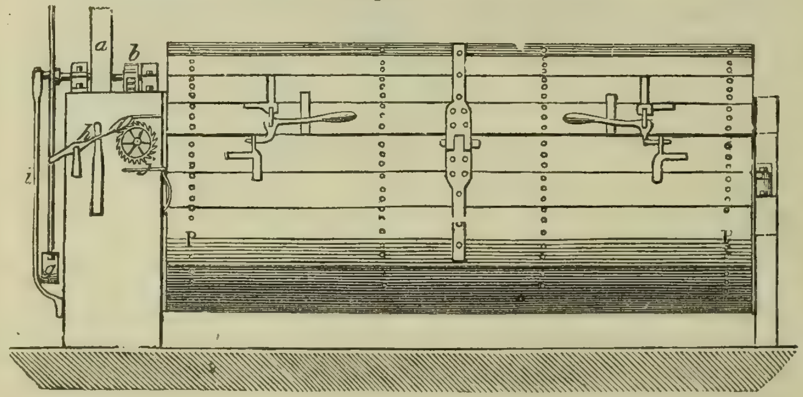


Fig. 15.



For this purpose, 165 lbs. of the dough are taken out of each of the compartments, B and C, making in the whole 330 lbs.; to this quantity about 200 lbs. of flour, and 100 lbs. of water—about 10 gallons—are added; the united weight of which is about 630 lbs. The two compartments are again replenished with the original quantities of flour and water, to make up the mixture, as before stated; namely, 100 lbs. of flour, and about 50 of water, and the cylinder set working as before.

The same means which work the leaven in the compartment, A, suffice to make the paste or dough in the division, B. On opening the cover, any portions adhering to the sides or cross bars are scraped off, and the whole removed, after which a similar quantity of flour and water is introduced to prepare a second batch for the next oven. The water is generally raised to a temperature of from 77° to 86° Fahr. (25° to 30° C.) in cold weather, and about 68° Fahr. (20° C.) in summer. At each addition of water, from half to three-quarters of a pound of fresh dried yeast is distributed through it. While this fresh quantity is kneading, the paste already produced is turned out upon the table and moulded into shape, or oblong form. All the lots of dough of the size of one kilogramme—$2\frac{1}{4}$ lbs. nearly—called cleft loaves, are placed upon a cloth stretched over a board, a fold of which is raised between every two loaves. The cloth thus laden with from ten to fifteen loaves, is transferred to the wooden shelves in front of the oven. While under the influence of the moderate temperature in this antechamber, or *fournil*, the loaves rise well and easily, and after they have attained the proper size they are transferred to the oven, an operation termed *enfournement;* it is performed by putting each loaf on a wooden shovel dusted with coarse flour, and placing it on the sole of the oven, all being closely packed, but disconnected with each other. A long gas burner introduced into the oven enables the workmen to view every part of it and place the loaves in proper position.

The Oven.—Until of late, very little improvement has been effected in ovens, and those in use at present in many provincial towns resemble, even in minute details, that discovered in the excavations of Pompeii.

Figs. 16 and 17 are a ground plan and an elevated section of the oven in general use in most countries. The space, A, wherein the bread is baked, is of an oval shape, and the usual dimensions are 12 feet by 10. The bed may be made of clay, but firebricks or tiles are better, and in this country it is mostly constructed of such material. In many parts of the Continent the beds of the ovens are formed of hewn *tuff* stone. The arch which covers the bed is low, being at most only about $1\frac{1}{2}$ foot in height and the entrance door, B, is from 1½ to 2½ feet broad; through this opening, both the fuel which heats the oven and the bread to be baked are introduced. At the back of the oven, three flues, *a a a*, are situated, and these come in a horizontal direction to the front of the oven, where they unite before entering the chimney, D. The smoke from the fuel is carried off through these flues, the draught of which is partly shut off by means of the damper, *b*. C is the space where the charcoal which is made in the oven is kept, and the pit, *c*, is provided to bring the workman on a convenient level with the door, to enable him to deposit the bread in the oven. E is the bakehouse, which is retained at the proper temperature for raising the dough by the superabundant heat from the oven and flues. The fuel in the oven is kindled by introducing a piece of lighted firewood through a small aperture in the door. As the draught of the oven is never very strong, the fuel often employed to heat it is thin boards, or brushwood, which readily ignites, as by the use of large logs the oven would not be heated properly. All the heat is derived from the flame from the wood; as soon as the charcoal begins to glow it is abstracted, and the bed of the oven prepared for the reception of the bread. In many ovens which are not of large dimensions, and which are fed with very thin wood, the anterior flues are not supplied, but two small apertures rising in the arch at the front answer the purpose, and sufficient air enters by the door. Much heat is lost by this mode, but the loss is partly covered by the charcoal produced. In many villages turf is used, and is found to answer better than wood.

Fig. 16.

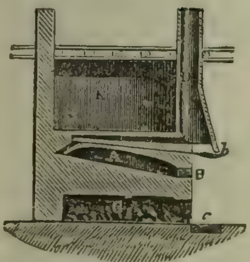
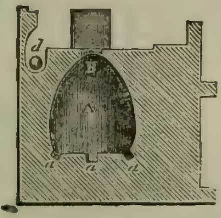


Fig. 17.



It is well known that the back part of the oven is warmer than the front, therefore to insure an even temperature the glowing coals are kept for some time near the door of the oven, to raise this part to a higher degree of heat. An hour's heating is always sufficient to bring the oven to a proper temperature, and sometimes half an hour will serve the purpose; the quantity of fuel is also continuously decreased, till a constant temperature is attained. The fuel being consumed and the charcoal withdrawn, the bottom of the oven is thoroughly cleansed out with a brush and moist cloth or swab. The heat of the oven is next proved by casting in a small portion of flour; if this assumes only a brownish colour, the proper degree is said to be attained, but if it should be charred, the introduction of the bread is delayed till the proper temperature is reached. The workman now introduces the bread, by placing two or three of the prepared loaves which had been hitherto left to rise, and are found considerably enlarged, each time upon the peel, the latter being slightly dusted over with a little bran, or refuse flour, to prevent the adherence of the dough; a lamp or gas light being placed beside the door and within the oven to illuminate the hearth, so that he can conveniently arrange each loaf in its proper position. When the whole of the batch has been introduced, the door is closed and made air-tight by a little cement or plaster. In the course of from twenty minutes to half an hour the batch is examined, and, if requisite, some of the loaves from the further end are changed to the front and colder part of the oven, those from the front being put to the back, after which the door is again closed and sealed till the bread is baked. The time required in this operation is dependent upon the construction of the oven, as also upon the size of the loaves; but it generally extends from one and a half to two or two and a half hours. Heat is derived during the baking from the hearth and elliptical arch of the oven; the former yields it by contact, and the latter by radiation. When the baked bread is withdrawn, the oven still remains very hot, but is incapable of baking another batch; it must, therefore, be heated with a further portion of fuel, to bring it to the proper temperature; the quantity required, however, is considerably less than what was used in the first instance. In the London bakehouses there is some slight alteration in the form of the oven, owing to coals being used instead of wood, but the principle of construction remains the same.

Of late years ovens continuously heated have been constructed. In Germany, one of considerable repute is erected at the military bakehouse in Hanover. This oven is heated by two furnaces; the bed of the oven is supported by numerous pillars erected upon the foundation, and the flues recede beneath it from the fire, and return along the arch at the top to the chimney; portions of the flame pass off laterally, and meet over the head, that the heat applied at the neck of the oven may be equalized with the hinder part. This oven is capable of baking, at each operation, 300 loaves of 7 lbs. each, or 2100 lbs. of bread; the fuel consumed being only 6·4 cubit feet of coal.

In Paris, famed for the beauty and quality of its bread, the model bakehouse of Mouchot is upon a similar principle. The kneading cylinders used at this establishment have been already referred to, and now the general arrangement and its other appendages will be considered.

Fig. 18 is a ground plan of the bakehouse, the upper part of the building being laid out as a granary, whence the flour is let down to the bakery as required. In this figure, *b b* are the baking ovens; *c* is the kneading apparatus; *d*, the space for the lift for raising the bread into a store-room in the upper part of the building; *e*, a space common to the two ovens, and into which the hot air passes; *f*, the wheel which gives motion to the machinery for making the dough.

Figs. 19 and 20 are elevated sections on the line, x—x.

This oven is called by the French *four aérotherme.* The corresponding parts are indicated in the following figures by the same letters. A is the fire-grate whereon the fuel, which may be pit coal or coke, is consumed, and *j* the ash-pit; this fire is surmounted by an arch, and the flame and heated air ascend by two spaces, *e*—Fig. 20—and pass under the hearth or bed of the oven, F F, in the channels, E E. B B are chambers at each side of the grate, wherein the air is heated without coming in contact with the fire. From these reservoirs the warm air enters the oven by two apertures, one of which opens directly into it, while the other communicates with the flues, so that the air may be more highly heated by coming in contact with the products of the combustion, and which are carried off through those spaces. The sole or bed of the oven is at first heated with dry wood, as the ordinary ovens, but when once the proper temperature is attained, it is kept up by the warm air which is admitted into the oven in the manner described, and by the hot air which is always passing along the flues, E E, beneath it. During the baking, the air which enters the oven becomes saturated with moisture, and in this state passes off at the top, by an opening which connects it with the reservoir, B, from whence it returns as before through *a a*, as long as the oven is at work. D is the chimney, and G G is an inclosed space to act as an insulator to the oven, and which is used to heat the dough previous to its being placed in the oven.

Fig. 18.

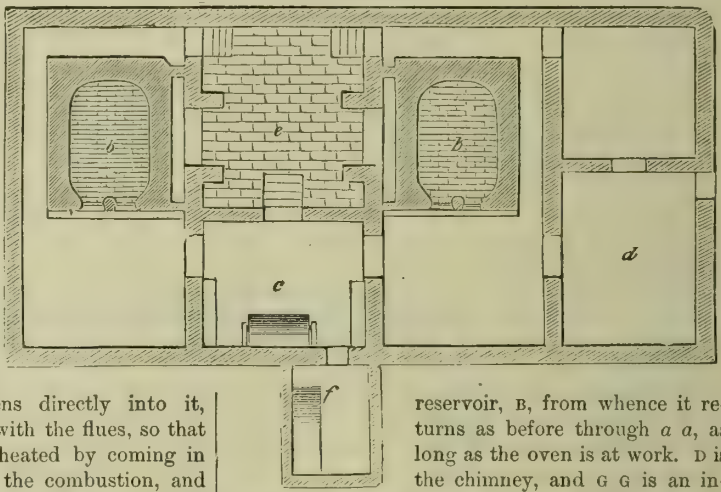
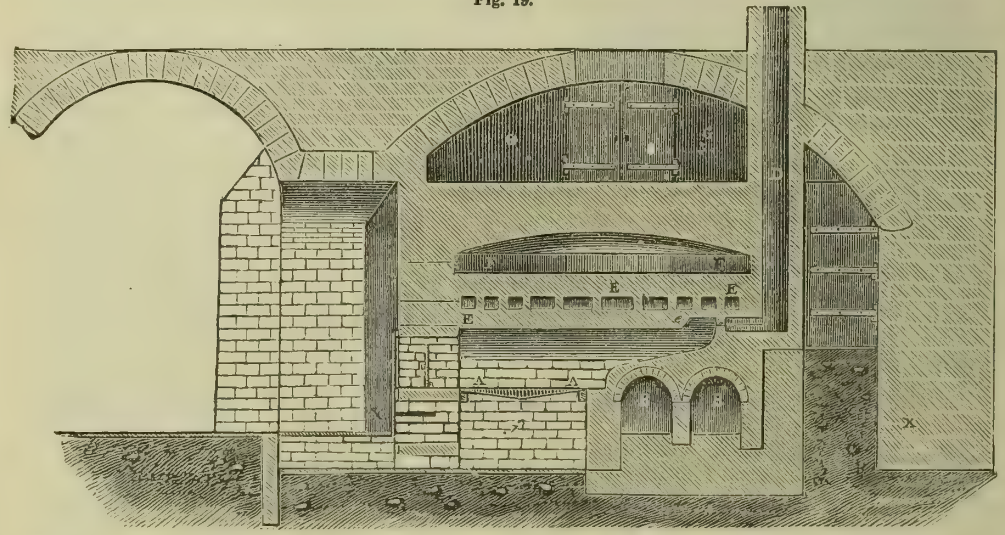


Fig. 21 is a front view of the oven, showing the doors at *p p*. When the oven is charged and the two doors shut, the two registers are thrust in to avoid firing the dough too much. But as soon as the temperature falls from 572° to 554° Fahr. (300° to 298°·8 C.), the registers are opened, to bring up the temperature to what it was at first, by permitting the circulation of warm air, which comes into the interior of the oven from the cavities below, situated round the furnace.

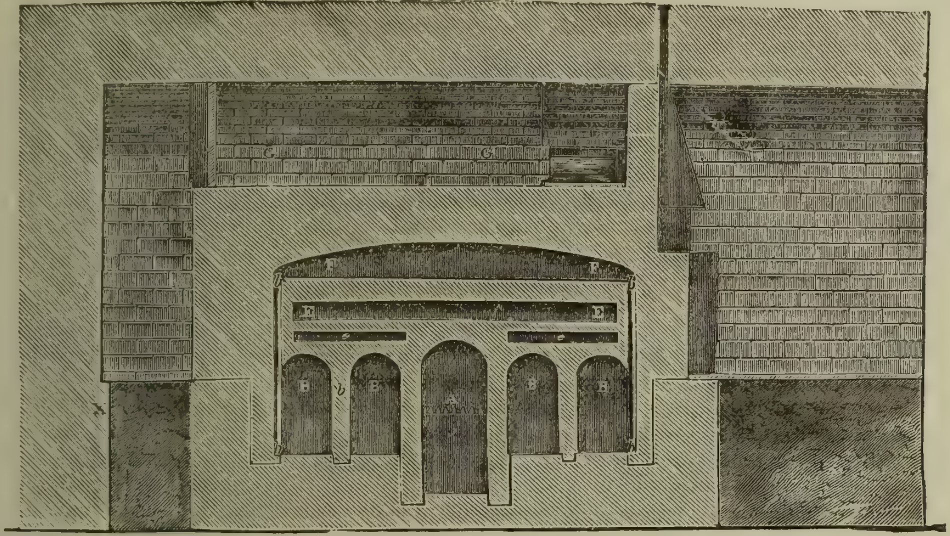
Fig. 19.



If the temperature has been sustained at about 572° Fahr. (300° C.), which is easily managed by inspecting the exterior tube of a thermometer fixed with its bulb in the interior, 300 kilogrammes of dough, divided into 1 kilogramme loaves, will be fired in twenty-seven minutes. The charging of the oven having occupied ten minutes, and the clearing about the same period, each baking, therefore, occupies a period of forty-seven minutes.

On reviewing what has been already said, it will be seen how much better adapted wheat flour is for the preparation of bread, than that of the other cereals. When flour from barley, oats, or rye, is made into a dough and fermented, the carbonic acid is, owing to its want of tenacity, not retained as in the dough from wheat flour; hence, when a dough made of any other flour than wheat is fermented and baked in the usual way, the bread produced, besides being inferior in colour, is dense and only very imperfectly "piled."

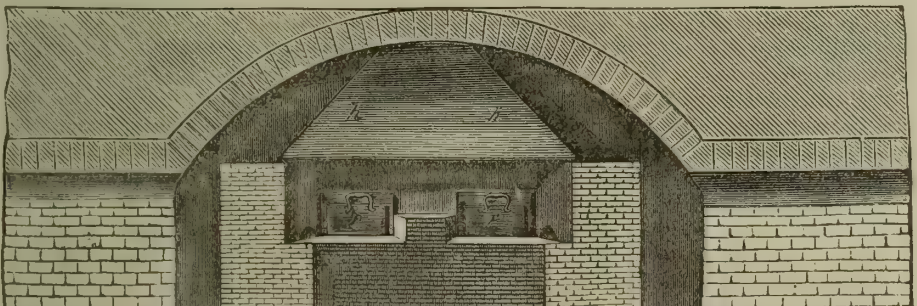
Fig. 20.



A marked difference is to be observed between the exterior part of a well-baked loaf and its interior; the former is of a light-brown colour, hard and thick; while the latter is soft, white, elastic, and interspersed with numerous cells: these differences are brought about by the chemical action of the heat applied in the oven, but in what manner has never been fully ascertained.

Reichenbach attributes the brown colour of the crust to the presence of a peculiar body which he calls "assamar," from *assare*, "to roast," and *amarus*, "bitter." He prepares it by toasting thin slices of bread, treating the powdered toast with alcohol, and evaporating to a syrup, and repeating this treatment till he obtains a residue soluble in alcohol; the assamar is then precipitated from this solution by ether. The same body is produced when meat, sugar, gum, starch, and other substances are roasted.

Fig. 21.



Starch can be readily detected in any part of a loaf; on moistening it with a solution of iodine a blue colour quickly makes its appearance. By macerating the bread with water, and acting upon the extract with a little diastase or malt extract, the starch, which was at first easily detected, will in a short time be no longer detected by the most delicate tests.

The crumb of bread is regarded by Knapp as merely an intimate mixture of starch paste with gluten, the separation of which may be effected by washing with water in the usual way for removing the starch from the crude gluten.

UNFERMENTED BREAD.—Two varieties of this kind of bread are to be met with. One consists of merely flour and water, with a little salt as a seasoning. Wheat flour thus treated is always made into biscuits. Rye, oat, or barley flour is thus invariably used, as their want of gluten excludes them from being used for making ordinary bread. The flour of these cereals is often mixed with wheat flour in biscuit factories; it cannot be used alone, as the dough is not sufficiently elastic to be extended into thin sheets.

The other variety of unfermented bread is made of wheat flour, and in loaves the same as those already described. As the raising of a loaf is merely a mechanical action of the carbonic acid and spirit, it occurred to some chemists, that if the carbonic acid could be supplied without causing a fermentation in the bread, the whole of the sugar might be retained, and the bread would be more nutritive.

Various means were resorted to to effect this result, such as kneading the flour with water saturated with carbonic acid, mixing bicarbonate of ammonium with the flour, &c. Dr. WHITING proposed, in 1837, to mix an alkaline carbonate with the flour, and to knead the mixture with water acidified with hydrochloric acid, in the exact proportion to convert the soda employed into chloride of sodium, while carbonic acid was disengaged to distend the dough.

Butter or other oleaginous matter, as also bicarbonate of sodium and tartaric acid (constituting the so called baking powders), are likewise in constant use for raising the dough; the former is used by confectioners for making pastry, and the latter, like the preceding mixture of carbonate of sodium and hydrochloric acid, for making loaves.

When butter is used, it is mixed with the dough, which is then rolled out into a thin sheet, and recoated with a thin layer of butter; after which the operator folds the sheet of dough outwardly from him; he next rolls it out as before, and lays on a second coating of butter, and proceeds as in the first instance, till the mass has been rolled and buttered eight or ten times. Some only butter the dough once or twice, and then repeatedly roll it in the same direction as above described.

When such a sheet is placed in the oven, the heat causes the disengagement of elastic vapour from the water, which finds free vent between the numerous layers of dough separated by the diffused fatty matter; these then swell up, thereby giving that peculiar puffy construction to the baked material, which is a characteristic of this kind of bread. Although each layer is partly distended from the adjoining ones, yet the bread as a whole is not light, for the substance of each stratum remains dense and consequently hard of digestion.

Sesquicarbonate of ammonium ($(NH_4)_4H_2(CO_3)_3$) has been used to a considerable extent in confectionaries, and also in making the finer kinds of bread. This salt, on being slightly heated, is split up into carbonic acid, ammonia, and bicarbonate of ammonium, $(NH_4)HCO_3$, all of which are volatile.

In practice the ammonium sesquicarbonate is powdered, and then either mixed with the flour, or dissolved in the water used to make the dough, so that on subsequently kneading the flour with this saline solution, the salt is equally disseminated throughout the mass.

The dough, during the kneading, evolves the characteristic odour of ammonia; the taste is likewise peculiarly saline; but all these peculiarities disappear during the baking, as their source is expelled by the heat. All the ammoniacal salt is not, however, driven off from the loaf, for a careful examination of the crumb will prove the presence of ammonia; but the free alkali is disengaged, and therefore no pungent smell remains.

Carbonate of sodium and hydrochloric acid are used, as already noticed, for raising the dough without destroying any part of the valuable constituents of the flour. The alkaline salt is mixed intimately with the flour, after which the proper quantity of hydrochloric acid necessary to replace the carbonic acid, is mixed with the water, and the dough made. This method was revived in 1848 by Mr. SEWELL, who took out a patent for it. His process was to place the flour in a tub, and to add hydrochloric acid, by means of a series of radial tubes, in the proportion of 45 ozs. of specific gravity 1·14 (containing about 28 per cent. of real acid) to 280 pounds of flour. This flour is made into dough by first adding finely powdered carbonate of sodium in the proportion of 63 grains to the pound, and then the proper quantity of water; the kneading and baking is conducted in the usual way.

Many medical men object to this method of bread-making, as it is calculated to introduce more chloride of sodium into bread than is deemed good for the health of the consumers: moreover, it is almost impossible to obtain commercial hydrochloric acid free from arsenic.

Bicarbonate of sodium and tartaric acid, mixed in equivalent proportions, are likewise substitutes for yeast. The result of their action is the same as the preceding; instead of chloride of sodium, however, tartrate of sodium is formed. A mixture of bicarbonate of sodium and tartaric acid is largely retailed under the name "baking powder."

A patent was many years ago taken out for a mixture of flour with other ingredients, having for its object the rapid making of bread. To each cwt. of flour put 10½ ozs. of finely-powdered tartaric acid of the best quality, and as dry as possible; mix it well with the flour, and pass the whole through a dressing machine, after which allow it to remain untouched for two or three days, that any water present may be absorbed by the flour; afterwards incorporate with the flour 12 ozs. of bicarbonate of sodium, 24 of chloride of sodium, finely powdered and dry, and 8 of ground loaf sugar; mix the whole well, and pass it through a flour dressing machine, when it will be ready for use.

This process is here mentioned, because, though at the time it was unsuccessful commercially, it has of late years been revived, and flour so prepared is somewhat largely advertized.

The bread made from flour mixed with tartaric acid and bicarbonate of sodium has a whiter colour than that made with yeast; it is, however, very plastic, and wanting in that lightness and spongy texture which characterizes well-made fermented bread.

Dauglish's Process.—As before remarked, the vesicular character of ordinary bread results from the development of carbonic acid gas uniformly throughout a mass of fermenting dough, whereby a loose spongy texture is imparted to what would otherwise be a dense sodden mass of baked flour and water.

In fermented bread the carbonic acid gas generated within the substance of the dough, is a product of the degradation of certain constituents of the flour, namely, the starch and sugar. In DAUGLISH's process the carbonic acid gas is produced independently, and superadded to the flour, which consequently undergoes no degradation whatever.

Carbonic acid, stored in an ordinary gas holder, is pumped therefrom into a cylindrical vessel of water; the water thus becomes charged with the gas. This carbonic acid water is mixed under a pressure of 100 lbs. on the square inch with the flour. The resulting dough, on the removal of the pressure, immediately becomes vesicular; it is then divided into loaves, and baked in a travelling oven.

The advantages of this process are, according to Dr. ODLING ("Brit. Assoc. Rep." 1859, p. 75)—(1.) Its cleanliness. Instead of the dough being mixed by the naked hands or feet, the bread, from the first wetting of the flour to the completion of the baking, is not even touched by any one. (2.) Its rapidity. An hour and a half serves for the complete conversion of a sack of flour into baked 2 lb. loaves. (3.) Its saving of labour and health. It substitutes machine labour for manual labour of a very exhausting and unhealthful character. (4.) Its economy. Despite the heavy prime cost of the apparatus, yet the use of carbonic acid is found to be cheaper than that of yeast. Moreover, the waste of the saccharine constituents of the flour, necessary in the old process, is avoided in the new one. (5.) Its preventing any deterioration of the flour. In making fermented bread from certain varieties of flour, the prolonged action of warmth and moisture induces a change of the starchy matter of the flour into dextrine, and the bread thus becomes sodden and dark coloured. This change is usually prevented by the addition of alum; but, in operating by the carbonic acid process, there is no time for the change to take place, and consequently no advantage in the use of alum. (6.) The character of the bread. Chemical analysis shows that the flour has undergone less deterioration in bread made by this process than in that made by the ordinary one.

BISCUIT MAKING.—Two classes of biscuits are made—"ships' biscuits" and "fancy biscuits." The former are made of flour and water only. The latter contain, in addition, other ingredients, such as butter, sugar, eggs, spices, &c.

Since 1831 ships' biscuits have been made by machinery, invented by T. T. GRANT of the Royal Clarence Yard. His apparatus consists of a kneading trough, in which a shaft carrying knives works with great rapidity, in order to mix the flour or meal and water into biscuit dough; and two cylinders, of about fifteen hundredweight each, the first of which is called a break-roller, and serves to knead the dough, and the second to spread the paste kneaded by it to the proper thickness of the biscuit before it is cut; these are worked by steam. The break-roller is erected upon a stout table, and can be raised or depressed at pleasure. A heap of the dough from the kneading-trough is placed at one side by two attending workmen, and the roller being temporarily elevated, the dough is pushed under it, when it is brought down and set in motion; by this means the mass is flattened into a sheet and carried to the other side. By reversing the motion of the roller, and lowering it still further, the sheet is rolled back, when the workmen receive it and fold it up in breadths. The dough is made to pass through the rollers three times. As the dough is discharged from the roller the third time, it is about two inches thick, and is then cut into pieces about half a yard square. The operation with the break-roller occupies about five minutes, the dough being kneaded much better than if done by the hand.

The second roller spreads out the squares of dough produced by the first operation to the size of 6 feet by 3, thus bringing the sheet to the proper thickness. The biscuits are then shaped by a cutting press.

The under surface of the cutting press is composed of a series of sharp knives of a hexagonal shape, which cut a piece of dough a yard square into sixty biscuits of a similar form. In some manufactories the stamping or cutting of the biscuit is effected by a roller having circular knives; in this case, however, the sheet of biscuits cannot be immediately introduced into the oven, as there is a space between each circle, and the biscuits have to be picked out separately and laid upon trays. In either case the cut dough is introduced as soon as possible into the ovens, which are very spacious, and heated either by hot air or by a continuous fire, the flues from which pass under and over the baking compartment: in the course of ten to fifteen minutes they are taken out.

The baking ovens are of fire brick and tile. Each one is 13 feet long, 11 feet wide, and 17½ inches in height. They are heated by separate furnaces, so constructed that a blast of hot air and fire sweeps through them, and brings them to the requisite heat in a very short time.

Mode of Working.—The first operation consists in mixing the meal and water; thirteen gallons of water are first introduced into the trough, and then a sack of the meal (which is ground and dressed at the government mills), weighing 280 lbs. When the whole has been poured in by a channel communicating with an upper room a bell rings and the trough is closed. The kneading knives are then set to work. The mixing operation lasts one minute and a half, during which the knives or stirrers make twenty-six revolutions.

The next process is to cast the lumps of dough under the breaking-rollers. The dough is thus formed into large lumps 6 feet long, 3 feet broad, and several inches thick. At this stage the kneading is still very imperfect, and traces of dry flour may be detected. The masses are now drawn out and cut into a number of smaller ones, about a foot and a half long and a foot wide, and again thrust under the rollers, this drawing out, cutting, and rolling being repeated until the mixture is so complete that no inequality can be detected in any part of the mass.

It should have been stated that two workmen stand, one on each side of the rollers, and as the dough is flattened out, they fold it up, or double one part upon another, so that the roller in its progress squeezes these parts together and forces them to mix. The dough is next cut into small portions, and being placed upon large flat boards, is by machinery conveyed to the extremity of the baking-room. Here it is received by a workman, who places it under the "sheet-roller." The kneading is here completed. The cutting is effected by the cutting-plate, consisting of a network of fifty-two sharp hexagonal frames, each of the size of a biscuit. The cutter is moved slowly up and down by machinery, and the workman, watching his opportunity, slides under it the cake of dough; the cutting-frame in its descent indents the sheet of dough without completely dividing it, leaving sufficient substance to enable the workman at the mouth of the oven to jerk the whole mass of biscuit unbroken into it. The dough is prevented sticking to the cutting-frame by the following device:—Between each of the cutter-frames is a small flat plate (figured with any desired marks), which is free to move up and down, and is loaded with an iron ball weighing several ounces. When the cutter comes down upon the dough, and cuts out fifty-two biscuits, each of these plates yield to the pressure, and is raised up; but as soon as the great frame rises, the weight of the balls acting upon the plates thrusts the perforated sheet off.

One quarter of an hour is sufficient to bake the biscuits, which are afterwards placed for three days in a drying room, heated to from 85° to 90° Fahr.

Fancy biscuits are made and cut into the desired forms by machinery. Captains' biscuits are composed of 10 quarts of water or milk and 15 lbs. of butter to the sack of 280 lbs. of flour; the well known Abernethy biscuits of $8\frac{3}{4}$ quarts milk or water, $17\frac{1}{2}$ lbs. of butter, $17\frac{1}{2}$ lbs. of sugar, $17\frac{1}{2}$ lbs. of carraway seeds, and 280 lbs. of flour.

The butter is mixed with the flour in the dry state, and then the water or milk in which the sugar has already been dissolved, added, and the whole made into dough by a kneading machine.

The temperature of the oven is an important point with the biscuit baker, his object being to bring the materials to a pale brown colour without burning them. Biscuits containing sugar should not be raised to so high a heat as those which are without it. The time usually required for baking is from ten to fifteen minutes.

To give additional lightness, it is the practice of some bakers to add a little sesquicarbonate of ammonium.

Yeast biscuits have, in addition to the other materials, from $4\frac{1}{2}$ to 5 lbs. of yeast to the sack of flour.

ADULTERATION OF BREAD.—Few articles have been subject to such open and flagitious adulterations as bread.

The adulteration of bread now practised, consists either in the mixing of fine flour with that of an inferior quality (the bread made from this compound being sold as of the best description); or of so mixing and otherwise treating the dough as to secure the retention after baking of an abnormal quantity of water.

Mouldy flour, the flour of rye, barley, oats, beans, and rice, and sometimes potatoes in a boiled and crushed state, are frequently used for these purposes.

A very frequently adopted method for securing the retention of a large quantity of water by the bread is "slack-baking," or under-baking. This is usually effected by introducing the dough into an over-heated oven; the outside of the loaf is rapidly browned, whilst the interior remains uncooked. According to URE, a baker by this means sometimes obtains as many as 106 4-lb. loaves from a sack of flour, and by the addition of boiled rice to the dough as many as 116 quarter loaves from 280 lbs. of flour.

The quantity of water in bread is determined by heating a known quantity for some time at about 212° Fahr. Good new bread should contain at most 45 per cent. of water.

The most frequent adulterant of bread is alum. It enables the baker to use damp flour, which has already undergone to an exaggerated degree the change which always takes place to a slight extent in the process of bread-making, and which consists in the conversion of the starch into sugar and dextrin. Alum stops this change, and for this reason some chemists justify its moderate use by bakers.

Dr. ODLING says:—"One very important use of alum is to prevent any undue deterioration of the starch during the process of raising or baking. If we mix a solution of starch with infusion of malt, in the course of a few minutes only the starch can be no longer detected, being completely converted into dextrin and sugar; but the addition of a very small quantity of alum either prevents entirely, or greatly retards, the transformation. The action of diastase on starch is very gradual, but here also the interference of the alum is easily recognizable. Bread made with infusion of bran or infusion of malt is very sweet, sodden, brown coloured, and so sticky, as almost to bind the jaws together during its mastication. But the addition of alum to the dough causes the loaves to be white, dry, elastic, crumbly, and unobjectionable, both as to taste and appearance.

"The worse the character of the bread which the flour alone would yield, the more striking is the effect of the alum. That alum does oppose the transformation of starch into sugar during the process of bread-making is indisputable; and this action is quite sufficient to account for the whiteness, the dryness, and the non-adhesiveness which result from its employment."

LIEBIG's explanation of the effect of alum in purification corresponds with this view. He says that in damp flour there is produced, by a reaction of the gluten and starch, acetic and lactic acids, which render the gluten soluble in water, and that alum and other mineral salts renders this gluten again insoluble.

PAYEN entertained the same idea as LIEBIG. He says "that when wheat has been badly kept, or when moist flour has become altered during its warehousing or transport, from three to six thousandths of alum are occasionally added, so as, in some degree, to restore to the gluten the consistency that it has lost."

Lime water has been recommended by LIEBIG to effect the same result as that now accomplished by means of alum, and has been used to a considerable extent by the Glasgow bakers. Dr. ODLING has found by experiment that lime water acts quite as efficaciously as alum in preventing the action of diastase, and the consequent transformation of starch into sugar. It seems to have scarcely any action upon the fermentation induced by yeast, or at any rate a much less action than alum, which undoubtedly retards the process somewhat. It yields a very white agreeable bread, having a rather more porous texture than ordinary bakers' loaves, and being quite free from any sourness of taste or smell.

The following are the modes adopted for the detection of alum in bread:—

KUHLMANN's process was formerly much in vogue until its fallacious character was exposed by Dr. ODLING. It is as follows:—Incinerate about half a pound (3500 grains) of bread in a crucible, and after having pulverized the ash treat it with nitric acid. Evaporate the mixture nearly to dryness, dilute with half an ounce of distilled water, and add to the whole an excess of caustic potash solution; boil and filter; neutralize the filtered liquid with hydrochloric acid, and add a slight excess of ammonia. Collect the alumina thus precipitated in a filter, wash, dry, ignite, and weigh it. Every 100 grains of alumina correspond to about 467 grains of alum. Dr. ODLING examined the ashes of forty-six samples of wheat and other grains, with the result that in twenty-one instances he obtained the white precipitate said to be indicative of alumina and alum. He says KUHLMANN's process is possessed of rare merits. It will never fail in detecting alumina when present, and will often succeed in detecting it when absent also.

Dr. NORMANDY took 1500 grains of bread from the middle of the loaf, cut or crumbled the bread, and placing it on a platinum tray, exposed it to a cherry red heat until completely charred. The charcoal thus obtained he ground in a mortar into very fine powder, and then returned to the platinum tray and exposed again to a cherry red heat until reduced to a gray ash. This ash was then moistened with ammonium nitrate, and heated to redness to burn off the last remaining portions of charcoal. He then poured on the ashes a few drops of hydrochloric acid, and in the course of a minute or so washed the whole in a porcelain capsule, and evaporated to absolute dryness, in order to render the silica perfectly insoluble. The perfectly dry residue was then drenched with hydrochloric acid, boiled with water, and filtered. The acid filtrate was then nearly neutralized with potash, and the whole thrown on a filter, and after slightly supersaturating the strong alkaline filtrate with hydrochloric acid, carbonate of ammonium was added in excess, and if a white floculent precipitate made its appearance it was further examined by collecting a portion on a platinum hook and heating it. On moistening the mass with cobalt nitrate and again heating, if without fusing it assumes a beautiful blue colour, the presence of alumina is presumed. The filtrate should be examined for sulphuric acid; if alum had been present it should yield an abundant precipitate with chloride of barium.

W. CROOKES varies this process thus: he found the great difficulty was to devise a method of analysis which should not confound other things with alumina. It was easy to frame various modes of operating by which a minute trace of alumina could be detected; but these reactions were equally sensitive whether alumina was present or not. For the process which he has at last adopted he claims that, though tedious in its manipulation, it has at least the merit of not showing the presence of alumina when that body is absent. He proceeds thus:—

The bread, of which at least 500 grains should be taken, is first to be incinerated in a platinum or porcelain dish, until all volatile organic matter has been expelled and a black carbonaceous mass remains. The temperature must not be raised much beyond the point necessary to effect this. Powder the coal thus obtained, and add about 30 drops of strong sulphuric acid, and heat until vapours begin to rise; when sufficiently cool, add water and boil for ten minutes. Filter, and evaporate the filtrate until the fumes of sulphuric acid begin to be evolved, when 10 grains of metallic tin and an excess of nitric acid must be added, together with water, drop by drop, until action between the acid and metal commences. When all the tin is oxidized, add water and filter. Evaporate the filtrate until fumes of sulphuric acid are again visible, when more water must be added, and the liquid again filtered if necessary. To the clear solution now add tartaric acid, then ammonia in excess, and sulphide of ammonium. Evaporate the liquid containing the precipitate suspended in it in a dish, until all the smell of sulphide of ammonium has disappeared. Filter, evaporate to dryness, and ignite to get rid of the organic matter. Powder the black ash, boil it in moderately strong hydrochloric acid, filter, add a crystal of chlorate of potash, and boil for a minute. Now add chloride of ammonium and ammonia, and boil for five minutes. If at the end of that time any precipitate is observed, it will be alumina. From the filtered solution, if oxalate of ammonia be added, the lime will be precipitated; and if to the filtrate from this, ammonia and phosphate of sodium be added, the magnesia will come down.

Dr. C. MEYNNOTT TIDY says, to detect alumina thoroughly, char (not incinerate) 1000 grains of the crumb of bread in a covered platinum crucible. Powder the charred mass in a clean iron mortar, and put the powder into a glass flask with a narrow neck; add 2 drams of hydrochloric acid, half a dram of nitric acid, and 2 drams of water. Gently heat to dryness on a sand bath, when dry boil for a few minutes with half an ounce of water, containing an excess of pure caustic soda made by the direct oxidation of the metal; about 10 grains will be sufficient. Filter, and again boil the charred mass with 2 drams of water; filter through the same filter paper, and add the filtrate to the former one. This should be allowed to stand all night, so that the liquid may filter through completely. Carefully neutralize the filtrate with hydrochloric acid; add now 5 grains of phosphate of sodium, and then ammonia in slight excess, the precipitate is weighed as phosphate of aluminium, 100 parts of which represent 384 parts of crystallized alum. The main points to be attended to in this process are:—1st. Only to char the bread; to incinerate it is fatal, the alumina becoming changed to an insoluble form, and some of it dissipated as chloride. 2nd. To keep the solution in as small a bulk as possible. 3rd. To see that the precipitate is entirely phosphate. (NORMANDY'S "Chem. Analysis," ed. Dr. NOAD; 1875, p. 90.)

Some bakers buy rock alum in powder, and mix it up in certain proportions with salt; the majority, however, make use of an article known in the trade as *hards* and *stuff*. This consists of a mixture of alum and salt. It is kept in bags holding from a quarter to 1 cwt., and is sold by druggists, who supply either the baker or the corn chandler. It is not easy to ascertain the proportion of alum and stuff used in the preparation of bread; it may, however, be stated as a general rule, that the worse the flour, the greater is the proportion of these ingredients used.

Sulphate of copper, blue vitriol, was at one time a favourite adulterant with many bakers, particularly in Belgium and the north of France. The advantages which the bakers derive from it are numerous. They find it easy to use with it flours of a medium quality and mixed. The panification is more rapid, the soft part of the bread and crust have a finer appearance, and lastly, they are enabled to add a greater quantity of water.

Sulphate of copper exercises an extremely energetic action on the fermentation and raising of bread, even when the copper salt is used in the proportion of 1 grain of sulphate to 7½ lbs. of bread. The proportion which produces the greatest enlargement, or raising, is from one-thirty-thousandth to one-fifteenth-thousandth part.

The largest quantity of sulphate that can be employed, without detracting from the beauty of the bread, is one-four-thousandth part; in a greater proportion the bread is very watery, and presents large openings; with one-eighteen-hundredth of the salt the dough can by no means be "raised," all fermentation is arrested, and the bread acquires a greenish colour.

The effects produced by sulphate of copper in the fabrication of bread are nearly the same as those obtained with alum, but the latter must be used in much more considerable quantities.

To determine satisfactorily these very minute quantities of the copper salt which might be contained in the bread, M. KUHLMANN had recourse to the following method, which he put to the test by introducing with his own hand into bread mere traces of sulphate of copper; one part in seventy thousand, for example, which represents one part of metallic copper to about three hundred thousand parts of bread.

In a platinum capsule 200 grammes of bread are completely incinerated. The produce of the incineration, after being thoroughly reduced to a very fine powder, is mixed in a porcelain capsule with 8 or 10 grains of nitric acid. This mixture is submitted to the action of heat till nearly the whole of the free acid is evaporated, and only a pitchy paste remains, which is mixed with about 20 grammes of distilled water, assisting its solution by heat. It is then filtered so as to separate the parts not attacked by the acid, and into the filtrate a small excess of liquid ammonia is poured, with some drops of solution of subcarbonate of ammonia. After cooling, the white precipitate formed in abundance is separated by percolation, and the alkaline liquor is submitted for some moments to ebullition, to dissipate the excess of ammonia, and reduce it to about a fourth of its volume. This liquor being rendered slightly acid by a drop of nitric acid, it is divided into two parts: the one part is submitted to the action of ferrocyanide of potassium, the other to sulphide of hydrogen, or sulphide of ammonium.

If the bread should contain only *a seventy-thousandth part of sulphate of copper*, its presence will be rendered apparent by the immediate pink or rose coloration of the liquid, on addition of ferrocyanide of potassium, and the formation, after resting some hours, of a light crimson precipitate; or by the appearance of a slight fawn colour, with the subsequent formation of a brown precipitate, on addition of sulphide of hydrogen or ammonium.

Sesquicarbonate of ammonium is used to raise and whiten bread. As before stated, the whole of the ammonia is not expelled by the heat of the oven. The best way to proceed for its detection is to mash half a pound of the bread in cold distilled water, and after half an hour strain off the liquid, add a few drops of hydrochloric acid, and evaporate to dryness in a water bath; the dry residue is next treated with a little strong caustic potassa, when ammonia will be disengaged if present.

BROMINE.—*Brome*, *Bromure*, French; *Brom*, German; *Bromunium*, Latin. Symbol, Br. Atomic weight, 80.—This element was discovered by BALARD in 1826 in the mother liquor from salt works at Montpellier. In its nature bromine closely resembles chlorine and iodine, with one or other of which it is always found associated. The relations of these three bodies have been made the subject of some beautiful speculations by DUMAS. "Regarding chlorine, bromine, and iodine as a triad, between the first and last there is recognizable a well-marked progression of qualities. Thus, chlorine is a gas under ordinary temperatures and pressures, bromine a fluid, iodine a solid; in this manner displaying a progression in the difference of cohesive force. Again, chlorine is yellow, bromine red, iodine black, or in vapour a reddish violet. Here we have a chromatic progression; and strange to say, if we refer to the atomic or equivalent weights of the three, a numeral progression will be observable. Thus, the weight of chlorine is 35, of bromine 80, and of iodine, 125; and now, if the atomic weights of chlorine and iodine be added together and divided by two, the result will be the atomic number for bromine. Hence it follows, if we could cause the union of half an atom of chlorine with half an atom of iodine, we might hope to get, to form, to create an atom of bromine!"

At ordinary temperatures bromine is a liquid body, which when in quantity appears of a blackish-red colour, but when examined in thin layers hyacinth red. It is very volatile, giving off, when exposed to the air, reddish vapours. At —8° Fahr. (—22°·2 C.) it congeals to a yellowish-brown, brittle, lamellar, crystalline mass, which remains solid when the temperature is raised to 10° Fahr. (—12°·2 C.). Bromine boils at 137° Fahr. (58°·3 C.)—Andrews—giving off vapour of the density, according to Mitscherlich, of 5·54, 100 cubic inches of which at 60° Fahr. (15°·5 C.) weigh 167·25 grains.

Like the other elementary bodies, it is not altered by heat and light, and is a non-conductor of electricity. It is soluble in water, alcohol, and ether; it is a powerful bleaching element, destroying, like chlorine, the blue of indigo.

Organic matters are acted upon by it, and it is very destructive to animal life. It stains the skin yellow, but less intensely than iodine, and the colour soon disappears.

Bromine is very volatile; a drop put into a flask soon fills it with vapour, resembling that of fuming nitric acid, and a taper plunged into it burns for some moments, with a flame green at the base and red at the top, as with chlorine, and is then extinguished.

No anhydrous oxide of bromine is known, and of its oxygen acids, the existence of only one, bromic acid ($HBrO_3$), has been thoroughly established.

Tin, arsenic, antimony, and potassium produce vivid combustion when thrown into liquid bromine, and become bromides. Iron, copper, bismuth, and mercury, combine quietly with the vapour of bromine at ordinary temperatures, but if heat is applied, with incandescence.

Bromine dissolves sparingly in water and alcohol, but with great facility in ether.

Bromine replaces part of the hydrogen in many organic compounds. In this way bromacetic acid is formed. Steam and vapour of bromine passed through a red hot tube yield hydrobromic acid (HBr) and oxygen.

Bromine is found in all sea waters, and in the water of salt springs. It also occurs, together with iodine, in the ash of sea-weed. Bromide of silver is found native in Mexico and Chili. Some fresh water plants have been found to contain it in very minute quantity.

The source from which bromine is principally manufactured is bittern—the mother liquor of sea-water or saline springs, from which the chloride of sodium has been separated by crystallization. Its extraction from this liquid, though not a very complicated process, requires delicate attention. Its separation from the metals with which it may be in combination—sodium or magnesium—is dependent upon the greater affinity which chlorine has for these; and hence, when a current of this gas is transmitted through the solution, the bromine is liberated and a chloride of the metal is formed. That the bromine is disengaged is known by the orange-yellow tint it communicates. Care must be taken that an excess of the chlorine is not used in liberating it, lest a portion might be expelled. If the liquor be now boiled in a close vessel, red vapours of bromine are evolved, which are condensed into the liquid state in a receiver surrounded with ice. The bromine is afterwards purified by solution in ether. This process is not commercially available.

The method now most commonly employed is as follows:—

Having deprived the mother liquor of sea water or brine of as much of its salt as possible, by evaporation and crystallization, chlorine is developed in the liquor, which now contains the bromine principally as magnesium bromide, by acting upon peroxide of manganese (MnO_2) with hydrochloric acid, or if sufficient salt still remains in the mother lie, sulphuric acid may be substituted.

Kreuznach uses 1 ounce of the binoxide and 5 or 6 of commercial hydrochloric acid to about 4 quarts of the mother liquor, and distils the whole slowly by the heat of a sand-bath as long as vapours of bromine are evolved. To avoid loss by the formation of hydrobromic acid through decomposition of the magnesium bromide by water during concentration, Desfosses recommends previous saturation of the mother liquor with chalk.

Bromine is also extracted from the mother liquor from the ashes of seaweeds (*varec*). After the separation of the alkaline chlorides and sulphate, the liquid contains iodine and bromine in the proportion of about 8 of the former to 1 of the latter. The iodine is precipitated by passing a current of chlorine until no precipitate is given on testing a sample of the liquor (after filtration) with a solution of chlorine or iodide of potassium. Sometimes the iodine is precipitated (as cupreous iodide and free iodine) by a mixture of sulphuric acid and sulphate of copper. The reaction is:—

$$\begin{array}{ccccccccc} \text{Sulphate of Copper.} & & \text{Sodium Iodide.} & & \text{Sodium Sulphate.} & & \text{Cuprous Iodide.} & & \text{Iodine.} \\ Cu_2SO_4 & + & 2NaI & = & Na_2SO_4 & + & Cu_2I & + & I. \end{array}$$

The filtered liquor contains the bromine, and is submitted to distillation with a mixture of sulphuric or hydrochloric acid and binoxide of manganese, in the manner previously described.

The crude bromine obtained from any of the above sources is distilled over chloride of calcium, and the aqueous distillate well shaken with ether: to the ethereal solution caustic potash is added till all colour disappears (bromate and bromide of potassium are formed), and is then evaporated to dryness and ignited in a crucible, when the whole of the bromate is converted into bromide of potassium. From bromide of potassium, free bromine is obtained by distillation with suitable quantities of sulphuric acid and manganese binoxide.

Or the mother liquor of the varec, free from iodine, may be neutralized with baryta, evaporated to dryness, and the residue calcined; it then contains a mixture of chloride and bromide of barium, from which the latter may be separated by solution in concentrated alcohol (in which bromium chloride is insoluble). The barium bromide is then treated with sulphuric acid and manganese binoxide as in the other cases.

LEISLER separates bromine from mother liquors containing it, by adding bichromate of potassium and an acid, and heating the mixture. The bromine is volatilized and is collected in a condenser filled with scrap iron. The bromide of iron formed is dissolved by the condensed steam, and runs off from the receiver; from it free bromine, or any desired bromine compound, can be procured by the usual processes.

Bromine is used for photographic purposes; in medicine; and as bromides of ethyl, methyl, and amyl, for making HOFMANN'S blues, and for the manufacture of alizarine from anthracene, &c. For further details of the mode of preparation see IODINE.

CADMIUM.—See PAINTS AND PIGMENTS.

CALICO-PRINTING.—See DYEING.

CANDLE.—*Chandelle*, *Bougie*, French; *Licht*, *Talglicht*, tallow candle, *Kerze*, wax candle, German.—The principal materials used for making candles are tallow (*i.e.*, clarified animal fats), palm oil, paraffin, and wax.

The researches of CHEVREUL and BRACONNOT have made it clear that fats, as they occur in nature, are a mixture of the simple fluid and solid fats, olein, stearin, and margarin, in variable proportions, the fusibility of the compound fat varying as the solid or liquid constituents preponderate. Fats are divided into three classes—1, unsaponifiable fats; 2, saponifiable fats; 3, fatty acids, or soap acids.

Unsaponifiable fats (such as paraffin) remain unchanged after boiling with aqueous potash.

Saponifiable fats (glycerides) when boiled, or left long in contact with alkaline solutions, are resolved gradually into—1, fatty acids, which unite with the alkali and form a soap salt; and 2, glycerin.

The fatty acids combine with most bases to form salts, and can be displaced by stronger acids; they therefore are classed as organic acids. They are divided by their respective boiling points into volatile fatty acids and fixed fatty acids.

These results of CHEVREUL have been confirmed and extended by BERTHELOT and HLINTZ.

BERTHELOT has succeeded in reproducing fats by the direct union of the fatty acid and glycerin, water being thrown out of combination. HEINTZ has corroborated most of CHEVREUL'S work, and has shown that the fats in tallow and palm oil consist essentially of stearic, palmitic, and oleic acids, in combination with glycerin—stearin, palmitin, and olein are therefore glycerides; but differs from him by regarding the margaric acid, obtained by the saponification of natural fats, as a compound of palmitic and stearic acids.

Stearin yields 95·7 per cent. of stearic acid ($C_{18}H_{36}O_2$), melting at 156°·5 Fahr. (69°·2 C). Palmitin yields 94·8 per cent. of palmitic acid ($C_{16}H_{32}O_2$), melting at 143°·6 Fahr. (62°·0 C). Olein yields 90·3 per cent. of oleic acid ($C_{18}H_{34}O_2$), which is fluid at ordinary temperatures.

TALLOW.—Beef and mutton tallow are the animal fats most used for candle-making. They consist chiefly of stearin, palmitin, and olein, the stearin having the predominance, but varying in quantity with the species of the animal (beef contains less than mutton tallow), its age, and kind of food.

Beef fat or tallow has a yellowish colour and a peculiar odour; it is hard and brittle, dissolves in about 40 parts of alcohol, and melts at 100° Fahr. (37°·7 C.).

Mutton suet or sheep fat, when fresh, has very little odour, though it acquires in a short time a rancid smell, probably from decomposition of traces of albuminous matter, and also of the olein; this smell is stronger if the suet be exposed to the air. It fuses between 100° and 106° Fahr. (37°·7 to 41°·1 C.); it is white, hard, and brittle; quite insoluble in water, and only partially so in alcohol, 100 parts of which, at a density of 0·820, and boiling temperature, take up only about 2·3 of the fat. Mutton suet solidifies at 100° Fahr. (37°·7 C.); but in so doing its temperature rises to 111° Fahr. (43°·8 C.).

Lard or hogs' fat has of late years been much employed in the United States for the manufacture of candles, the olein being removed. The quality of the lard varies with the nature of the animals' food; for instance, the fat of hogs fed upon potatoes or grain is hard, and possesses great body. When the animals are fed upon malt, their lard is next in quality to the preceding; but the fat of such as consume distillers' wash contains very little body; and is besides soft, oleaginous, and of a yellowish colour. It fuses at 81° Fahr. (27°·2 C.).

All of these fats are separated from the cellular tissue and other matters by heat; the lower the effective temperature used the better will be the tallow. The operation is technically termed "rendering;" the department where the work is conducted was formerly called a "foundry."

The best time to render animal fat is while it is fresh; for when allowed to remain for a time before being worked, more especially if undried, it undergoes partial decomposition, which renders its after working into fine tallow very difficult.

The requisites for a foundry for purifying tallow and other fats are, a drying-house, steam-jackets or boilers, tubs, and presses. The fresh fat is strung up in the drying-house to harden it and to drive off the moisture. In a well-aired chamber long horizontal rafters are supported either by cords or upright pillars, and upon these the rough tallow is strung till it becomes dry. The tallow is then minced by appropriate machinery. In large foundries this is done by steam machinery; but in small melting works the tallow is chopped by a lever knife fixed upon a table.

The minced tallow is collected in a basket, and taken to the melting vat or boiler for the purpose of melting it.

In small factories the boiler is a copper vessel, so set that the flame from the furnace comes in contact with its bottom only; this is to prevent possible carbonization. To keep the "unrendered" fat from contact with the heated metal, a certain quantity of melted tallow, or a layer of water, is always retained in the bottom of the boiler.

The lower part of the boiler is generally the shape of an inverted cone, but the sides slope inwards towards its mouth, to prevent inconvenience from the spirting of the melted suet. The chopped tallow is thrown into the boiler, and the fire so fed as to communicate a moderate heat. As soon as the bath of rendered tallow on the bottom of the copper becomes melted, the entire contents are kept regularly stirred, till the fat is completely separated from the membranes which constitute the cells and adipose tissue. These contract after having burst and emptied themselves, and rise to the surface. They are technically termed "cracklings." When the melting is complete the rough tallow is ladled out into a large tub, whence it is afterwards removed to small ones, arranged on the floor of the foundry at equal distances from the boiler. A simple filter, consisting of a wicker or wire basket thickly woven, or a brass wire-gauze sieve, is placed on the tub to prevent the cracklings from passing through. Some melters press a filter sieve of coarse wire into the melting vat, and ladle out the liquid which rises through its meshes, passing it afterwards through a finer sieve placed upon the tub. Before distributing the melted fat into the smaller tubs, the contents of the larger one are allowed to deposit any impurities that may have passed through the sieve, but the tallow must not be allowed to solidify.

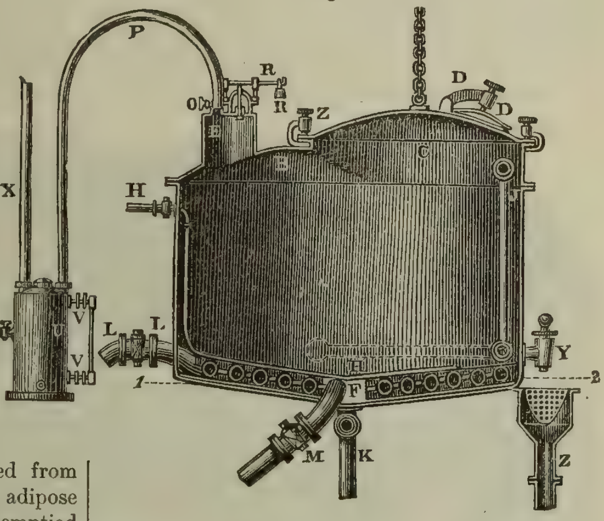
After all the liquid fat is removed the "cracklings," which still retain some fat, are thrown into boiling water; this melts the fat, which floats to the surface, when it is ladled out and boiled, to remove water from the suet; the cracklings remaining on the sieves and deposited in the tub are treated in a similar manner. The whole of the water cannot be thus separated, and therefore recourse is had to heat and pressure. Hydraulic presses, heated by steam pipes, are commonly used.

The cracklings are introduced while warm, and the power of the press exerted as long as any fat exudes. The residuary cake, which is known as "greaves," is sold as food for dogs and swine.

An ingenious mode of tallow melting has been devised by D'ARCET; it has, however, the somewhat serious drawback that the residues are useless as food for animals.

A jacketed copper pan, closed in at the top and of sufficient strength to resist 50 lbs. internal pressure on the square inch, is used as melting vat. The chopped suet is introduced through a man-hole in the lid, and steam passed into the jacket. Sulphuric acid, diluted with from 20 to 50 parts of water (according to the quality of the rough fat), is then added in the proportion of 1 part dilute acid to 100 parts of fat, and the lid of the pan firmly secured. The mixture is allowed to boil for several hours, the temperature being kept at from 220° to 230° Fahr. (105° to 110° C.). The animal membranes dissolve in the sulphuric acid, whilst the purified fat separates and floats on the top of the acidulated water. The tallow is drawn off by a tap at a suitable height, the tube of which pierces through the jacket to the interior of the pan, where it is continued by a flexible tube attached to a float, so balanced as always to be kept at the boundary of the two liquids.

Fig. 1.



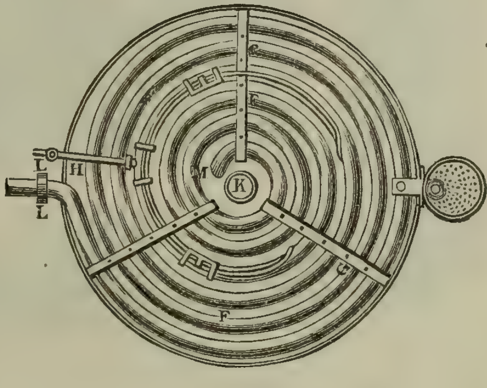


Fig. 2.

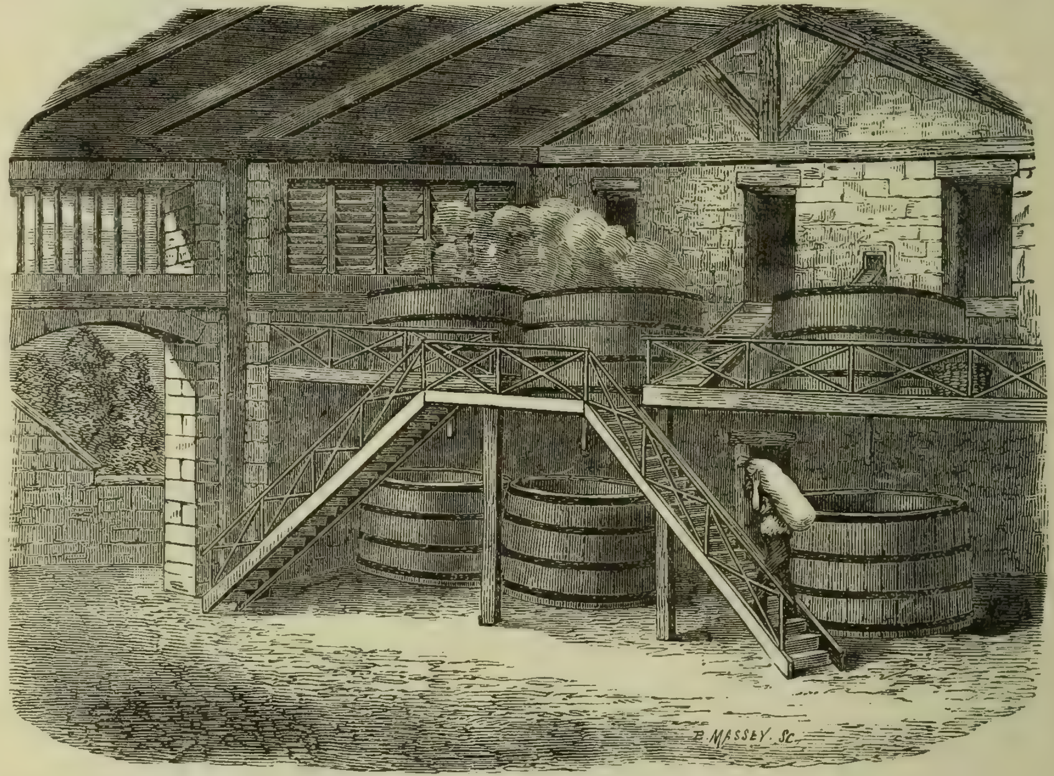
By this process 85 per cent. of pure white tallow can be extracted from ordinary rough fat.

Melting by fire yields only 80 per cent. of tallow, which is, moreover, apt to be discoloured by charring.

Fouché's process is an adaptation of D'Arcet's. Fig. 1 shows a vertical section of the melting pan, and Fig. 2 is a horizontal section (across the line, 1—2, Fig. 1).

The pan is furnished with a rivetted copper dome, B, which is provided with a manhole, C, through which the fat is introduced. The lid of the manhole is lifted by a chain passing over a pulley; to the other end of the chain a balancing weight is attached. D D shows an opening through which the progress of the operation can be observed. The lid is secured by a screw passing through the arm, D. The vapours are conducted away by the pipe, P. access to which is gained by opening the tap, O. On the cap, E, is a safety-valve, R R, with weight attached. The condenser, U, stops the greater part of the vapours given off; the remainder pass by X into the chimney shaft. V V is a gauge showing the contents of U. The boiler is heated by the steam worm, F, supported just above the bottom of the pan by the stays, G (Fig. 2). The steam passes in at I I, and the condensed water returns through N I to the boiler. The fat is kept in motion by a steam jet issuing from the small pipe, H H. The vessel is emptied by lowering the tube, J (which has a sieve at its upper end) until it falls into the position shown by the dotted line. The drawing-off tap is shown at Y. The pan is emptied of the acidulated water by the pipe, K.

Fig. 3.



1000 lbs. of rough fat and 80 lbs. of water are first introduced, and then $2\frac{4}{10}$ lbs. of sulphuric acid of 66° Fahr., diluted with 16 lbs. of water. The steam must have the temperature of 255° Fahr. (about 45 lbs. pressure per square inch). In the vessel itself half this pressure is sufficient, and the safety-valve on E is allowed to blow off when this is reached. The rendered tallow is run off by the pipe, Z, which has a sieve at the top to keep off coarse impurities.

Evrard of Douai uses a weak solution of caustic soda in place of sulphuric acid, to break up the fat cells.

The rough fat is placed in an ordinary cylindrical melting copper, heated by a furnace, or by steam, with 1 to 1·5 per cent. of soda dissolved in much water. The boiling alkaline liquor penetrates the membranes and breaks them up, so that the melting fat readily escapes from its enveloping tissue. The temperature is never allowed to exceed 212° Fahr. (100° C.).

Fig. 3 represents six vats for tallow melting by steam, seconded by the use of alkaline liquor. The steam pipe, by which the ebullition is effected, is visible at the bottom of the three upper vessels.

The heating is effected by simply passing high-pressure steam through the bottom of the vessels into the centre of the mass of fat.

Tallow as it comes from the melters is generally of a bad colour, besides being more or less rancid; it has therefore to be purified before manufacturing it into candles. Various processes have been tried at different periods for this purpose. By Watt's process the tallow is bleached by mixing with it sulphuric and nitric acids, together with bichromate of potassium and oxalic acid. When the fat is nearly melted in the steaming tub the nitric acid is added in the ratio of 1 lb. to a ton of tallow; but before introducing it, it is diluted with 1 quart of water and 2 ounces of alcohol, naphtha, ether, or spirit of turpentine, the whole being then boiled for half an hour; after which the fat is washed to free it from any particles of the materials employed in the purification. In this process the materials taken seem to neutralize the effect of each other, for, whilst the bichromate o' potassium and nitric acid supply oxygen for bleaching the fat, the oxalic acid and alcohol, or other liquor, divest these compounds, or the fat, of oxygen; however, the patentee alleges that the intended effects are produced to satisfaction.

A very effective process, which the editor had the opportunity of watching for some years, is to melt the tallow in any convenient vessel, over which a hood connected with the chimney shaft is fixed to carry off the disagreeable smell, and heating it by steam of greater or less pressure, from 170° to 230° Fahr. Streams of air are then forced through the molten tallow by means of perforated pipes placed at the bottom of the vessel, and a blowing apparatus to which they are connected. Unless the colour of the tallow is very bad, its bleaching will be effected in ten to fifteen hours. Even palm oil subjected to this treatment is brought to a cream colour in about twenty-four hours.

Some candlemakers improve upon this method by adding carbonate of potassium to the melted fat, agitating it, allowing it to repose, and when the whole of the sedimentary matter has settled down, then blowing the air through it as above.

By Watson's process the purification is effected by permanganate of potassium ($K_2Mn_2O_8$), "chameleon mineral." The purifying element in this case, as in those processes already described, is oxygen. In the present case this is derived from the reduction of the permanganic acid to sesquioxide of manganese, *i.e.*, manganic oxide (Mn_2O_3). The bleaching is executed by melting the fat in a leaden or wooden tank by means of steam, and gradually mixing it with a solution, in which the permanganate is dissolved to the amount of about 1-20th of the weight of the fat taken. When both are intimately mixed by brisk agitation, a sufficient quantity of dilute sulphuric acid to communicate a slightly acid reaction is added, in order to set free the permanganic acid of the chameleon mineral; the whole is then briskly stirred for about an hour, during which time the temperature of the mixture should be maintained at between 150° and 212° Fahr. (65°·5 to 100° C.), as may seem desirable. The contents of the tank are then allowed to rest, that the oily matters and the acid solution may separate, the former rising to the surface, from which it is drawn off into another vessel, and remelted in a fresh quantity of hot water and cooled, for the purpose of washing it. From time to time samples must be taken from the bath of melted fat, and cooled, to observe if the proper degree of whiteness is attained; and if extra purified tallow is to be produced, a fresh quantity of the chameleon mineral dissolved in water may be added.

Stearin and Stearic Acid.—In preparing stearin and stearic acid for candles, the object is not to obtain these bodies in a state of absolute purity, but to have them as free as possible from the oleic acid, glycerin, and fatty acids of low melting points, to which they are united in the natural fats.

Stearin, Tristearin, Stearate of Glyceryl $(C_{57}H_{110}O_6) = \left.\begin{matrix}(C_3H_5)\\(C_{18}H_{35}O)_3\end{matrix}\right\}O_3$.—Chevreul's stearin is obtained from mutton suet or tallow by dissolving it in boiling alcohol, and recrystallizing the fat which separates out, till the boiling point becomes constant. Lecanu melts mutton fat in the water bath with its own weight of ether, stirring all the time, and subjects the mass when cold to strong pressure, to remove the fluid constituents of the fat, and recrystallizes till the melting point rises to 62° C. After thirty-two crystallizations, however, the fat thus treated is still a mixture of tristearin and tripalmitin. According to Bonis and Pimental pure tristearin may be separated from Bridonia tallow by recrystallization, and yields by saponification an acid having the melting point of stearic acid. It is a white substance, and as it deposits from alcohol it forms snow-white, glistening scales; it is not greasy to the touch, is easily powdered, and melts at 125° Fahr. (51°·6 C.). It readily dissolves in hot alcohol and ether, but is almost insoluble in water and ether in the cold.

Stearic Acid, $C_{18}H_{36}O_2 = \left.\begin{matrix}C_{18}H_{35}O\\H\end{matrix}\right\}O$.—This acid is readily obtained by saponifying stearin with potassium hydrate, decomposing the soap formed with hot hydrochloric acid, collecting the flocculent stearic acid upon a filter, washing it with cold alcohol, and dissolving in boiling alcohol. The solution thus obtained is set aside to cool, when the stearic acid crystallizes out in white glistening needles or leaflets, which appear under the microscope as elongated lozenge-shaped plates. It is inodorous and tasteless, does not feel greasy to the touch, and dissolves in all proportions in boiling alcohol and ether, from which it separates on cooling. It melts at about 157° Fahr. (69°·4 C.) to a colourless oil, which on cooling solidifies to a white, scaly, crystalline mass. Impure stearic acid crystallizes in needles. The alcoholic solution of stearic acid gives a slightly acid reaction with blue litmus paper; it decomposes alkaline carbonates to the amount of one-half in the cold, and completely at the boiling point It burns like wax, and forms the chief ingredient of stearin candles, to which reference will be hereafter made.

The most convenient way of preparing stearic acid is the following:—Beef or mutton tallow is saponified with soda liquor, the soap decomposed by heating with water and dilute sulphuric acid, and when cold the fatty acids removed and washed with water. They are then dissolved in as small a quantity of hot alcohol as possible. On cooling the stearic acid separates, the oleic acid remaining in solution. After draining the precipitated stearic acid, it is subjected to strong pressure, redissolved in alcohol, and, after cooling, pressed as before. Pure stearic acid is obtained by fractional precipitation with acetate of lead, barium, or magnesium, when the stearate separates before the salt of palmitic acid.

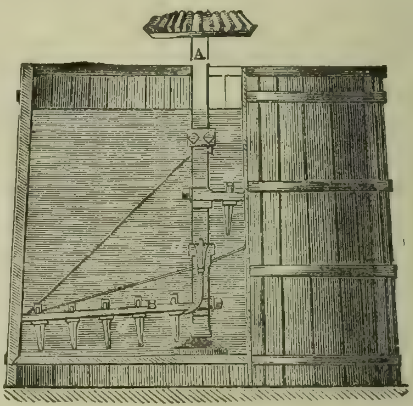
Chevreul's investigation on the fats was the first step towards the employment of stearic acid and stearin in the preparation of candles; additional information was added to that derived from the researches of this chemist by the labours of Braconnot and others; and ultimately the tallow treated according to the processes pointed out by them, and divested of its olein and glycerin, was used for the making of candles by Cambaceres. The manufacture, however, did not succeed on account of the imperfections of the methods adopted, which were such that better illuminating materials could be procured at a less cost than the new patent candles. On the Société d'Encouragement offering a premium of 4000 francs to the person who would discover a means of manufacturing a cheap, and at the same time good candle, the spirit of inquiry was excited by the munificent reward, and as the result a great improvement took place, which much lowered the cost of candles, while in point of quality they were considerably improved, instead of being deteriorated. From time to time various alterations have since been introduced in the method of working.

Gay-Lussac's patent, in 1825, specified that the fat, after being rendered, should be boiled with solutions of either potash or soda, in order to form a soap, and to remove the glycerin with which the fatty acids are united. The soap thus produced was next to be decomposed by an acid, in a capacious vessel, and in the presence of much water, the whole being heated by steam injected in any convenient way, and kept well agitated during the operation. After the decomposition was completed, the contents of the vessel were allowed to remain at rest for some time, till the fatty acids collected upon the surface of the water, which could be drawn off by a discharge-cock at the bottom of the tub, carrying with it the alkaline salts resulting from the decomposition of the soap. To free the fatty acids completely from any traces of the alkali or saline substances, a quantity of fresh water was thrown in upon the fat, the steam again allowed to enter, and the contents of the tub agitated as before; and after a short time the whole was left to cool, and finally the water drawn off from the solid layer of fatty bodies. The mass was then submitted to considerable pressure, in an apparatus similar to that used in extracting oil from seeds, by which means the liquid oleic acid was discharged, leaving crude stearic acid mixed with other fatty acids. Margaric acid was formerly supposed to be among those, but this was shown by Heintz to be only a mixture of palmitic and similar fatty acids of lower melting points. Lime is now employed instead of potash and soda, to set free the glycerin, and form lime salts with the several fatty acids. This greatly lessens the price of stearin candles.

The vessels employed in conducting these operations in most factories, are large wooden tuns closely covered, and into which a steam-pipe enters from an adjacent boiler. The suet or rendered tallow is introduced into these tuns and melted; then pumped out into a second tun of a similar construction, but supplied with machinery for agitating the contents.

The decomposing or saponifying tun is represented in the annexed woodcut—Fig. 4. It is constructed of oak, well bound with stout iron hoops, and covered tightly. In the centre of the tun a shaft, A, to which a bevelled cog-wheel, gearing into another fixed on the main shaft from a steam-engine, but which is not shown in the drawing, is appended. In the interior of the tun four brass arms, *d*, studded with large teeth, extend from the shaft, turning round with the motion of the axis, and keeping the contents in brisk agitation.

Fig. 4.



Heat is communicated by means of a convoluted steam-pipe placed at the bottom, and perforated with small holes. This pipe is furnished with a stopcock, for the purpose of shutting off the steam, or otherwise regulating it.

In this tun, the hydrate of lime is mixed with the fat in the proportion of 15 per cent. of its weight, the lime being made into a moderately thick cream with water—$1\frac{1}{4}$ gallon to 1 lb. of lime. Care should be taken to have the caustic lime as pure as possible: if it be not properly caustic, an increased amount of acid will be required to neutralize it. When there are many impurities in the lime these are with difficulty separated from the mixed acids afterwards. Having thoroughly blended the cream of lime with the tallow in the decomposing tun, the cover of which is fastened down tightly, the steam is turned on and allowed to play upon the contents for six hours, keeping the whole constantly agitated by the aid of the rotating stirrers provided for this purpose; at the end of that time the combination of the fatty acids with the lime is generally complete. The test by which the workman can judge whether the saponification is perfect is to take out a small portion of the thick mass, and allow it to deposit the insoluble lime soap; the supernatant water is then poured off, and the subsided matter cooled; if this mass appears smooth, homogeneous, and semitransparent throughout, makes a sharp noise on being fractured, and goes into powder on being ground in a mortar, there remains no undecomposed fat. The steaming in the vessel should be continued till the contents give these reactions. The steam is then shut off, and a quantity of cold water gradually added, keeping the machinery in motion during the time. This drenching with cold water causes the insoluble soap to assume a granular appearance, and take up the glycerin, and as soon as this is effected the agitation is discontinued. When, after a short interval, the whole has settled, the water, together with the glycerin of the fat, is drawn off by means of a plug hole at the bottom of the tun, protected on the inside by a sheet of fine copper, wire gauze, or cloth, so that the small particles of lime soap cannot pass out when the plug is removed. As soon as the whole of the water has run off, the outlet is stopped up, and more cold water poured upon the soap, and the mixture agitated; this is drawn off as before.

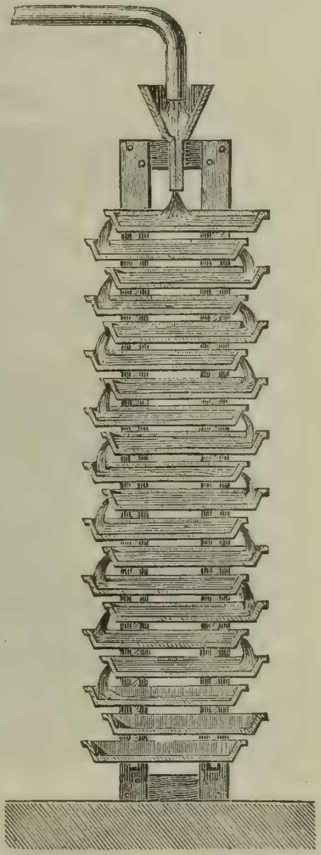
By such repeated washings the whole of the glycerin is removed, and nothing remains but the lime compounds with the stearic, palmitic, and oleic acids of the fat, together with the slight excess of lime which may have been taken to insure complete decomposition.

The next stage in the operations is the decomposition of the soaps and the removal of the lime. This is done by the addition of concentrated sulphuric acid, in the proportion of 250 lbs. of acid, diluted with 2000 lbs. of water to every 1000 lbs. of fat saponified. The dilute acid is gradually poured into the tun upon the soap, the mixture being heated by the steam coil to about 200° Fahr. (93°·3 C.), but no higher, and the whole is gently agitated till the decomposition is complete—a point ascertained by the disappearance of its granular structure as well as by the fatty bodies rising to the surface.

Much care is necessary on the part of the attendant during this period, in regulating the entrance of the steam, for if the temperature becomes too high, with the presence of a strong acid and exposure to air, the colour of the products will be injured. The tun may be left uncovered during the decomposition without any disadvantage arising. When the separation of the lime is complete, the contents of the tun are left to rest for some time, in order that the sulphate of lime may be entirely taken up by the water, and removed from the fats which occupy the upper strata. The plug hole at the bottom of the tun is then opened, and the solution of sulphate of lime, with any other lime salts or caustic lime that may be held mechanically in the liquid, is drawn off. Hot water is then let in, and the agitator set in motion; the warm water melts the fats, and the separation of any saline matter or excess of lime is facilitated. After the melting and agitation has been continued for some time, the contents are allowed to repose as before, and after the water and any impurities have settled to the bottom, they are drawn off through the outlet. The washing is continued till the last traces of the mineral compounds are separated, and then the crude fatty acids reheated to the melting point, and drawn off into casks or trays to crystallize.

The trays employed are made of tin, and have a capacity varying from 16 to 20 inches in length, 10 to 15 in breadth, and 2 to 3 inches deep; after being charged with the melted fatty bodies, they are ranged upon convenient shelves in an appropriate room, the temperature of which stands between 70° and 90° Fahr. (21°·1 to 32°·2 C.); here they remain for two, three, or more days, till the stearic and palmitic acids, &c., assume a crystalline form, or "granulate." Oleic acid does not solidify at this temperature, and at the termination of the granulation it may be observed upon the solidified matter on the trays in the form of drops or exudations. A very ingenious method of filling the granulating trays, the invention of M. Binet, is shown at Fig. 5.

Fig. 5.



When the mass in the tin tray has crystallized or granulated as far as possible, it is removed to a machine, where it is cut into thin slices by a knife attached to a revolving wheel, against which the fatty matter is pressed. The sheets of fatty acids are then interlaid with coarse matting made of jute or cocoa-nut fibre, or each of the cakes may be at once enveloped in a canvas or woollen bag, and placed under a hydraulic press, and the chief part of the oleic acid expressed.

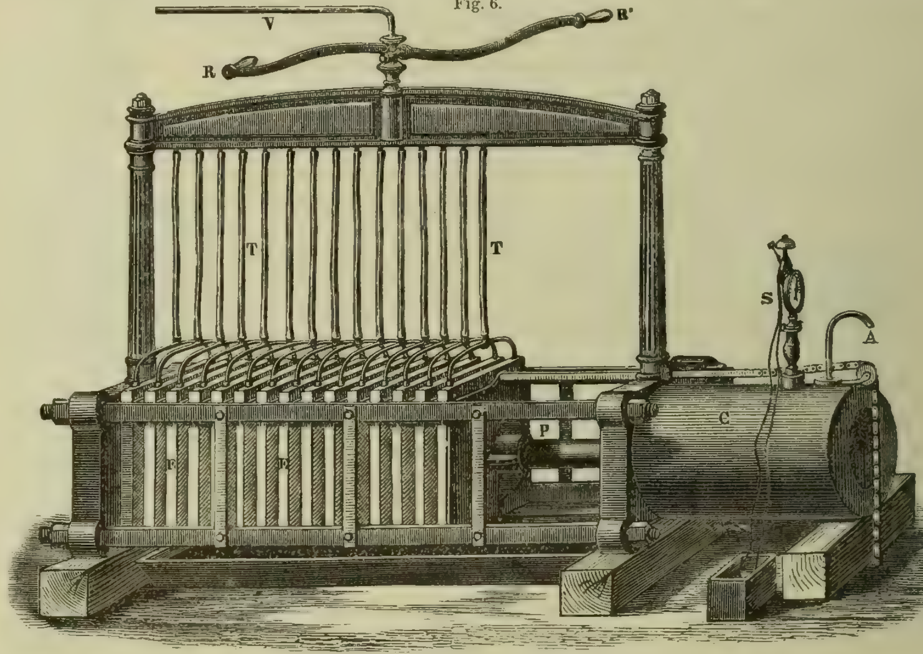
When placing in the press the sheets of fat interposed with matting, or enveloped, as the case may be, in coarse bags, plates of wrought iron, with turned up rims, are put in between the cloths at regular intervals till the frame is filled; the sheet-iron plates prevent the whole mass from being blended too tightly together by the great pressure, and in the channels formed by the rims the oleic acid is collected.

After the pumps have been set working, and the pressure has been exerted till no more fluid exudes, the machine is loosened and the expressed layers taken out. The fat, by means of this compression, becomes so dense and hard as to be scarcely marked by the nail. The cakes, however, still retain oleic and palmitic acids, to abstract which they are usually submitted to a second compression, under the influence of heat, particularly when the products are required for the best kinds of stearic acid candles. The cakes are inclosed first in canvas or woollen bags, and afterwards coarser ones, made of cocoanut or jute fibre, and placed between iron plates surrounded by hollow frames.

The form of press used is shown in Fig. 6. A is the tube by which water is forced into the cylinder, C, containing the hydraulic piston. A pressure gauge, S, indicates the degree of compression. P is the piston; E E, iron frames surrounding the bags containing the cakes of crude fatty acids, and which are heated by steam. The steam enters the press by the pipe, V, on opening the valve controlled by the lever, R R′, and descends the tubes, T, which are furnished with joints allowing the frames to move to and fro. After a sufficient amount of pressure the fat is taken out, and may be at once used for candle making. It then constitutes the mixture of stearic and palmitic acids known as stearin.

If any further purification is desired, the pressed cakes of fat are introduced into a large covered tub constructed of wood, and bound firmly with strong iron hoops; into this vessel steam is forced during five or six hours; it is then shut off, and when sufficient time has elapsed for the water to fall to the bottom, the layer of fatty acids is conducted into moulds and cooled.

Fig. 6.



In some factories the whole process is conducted by hand. The tallow is placed in large open wooden vats lined with lead, and heated by direct injection of steam through copper pipes. When the fat is melted, milk of lime is added in the proportion of 14 to 15 parts of lime to 100 of tallow. The mixture is kept boiling for eight hours, being agitated from time to time with a wooden paddle.

Steam is then shut off, and the decomposition effected by means of sulphuric acid, the lime soap being allowed to settle, and the sulphate of lime solution run off, as before described. Fig. 7 shows the general arrangement of the plant, the vats being so arranged that the process may be constantly going on at different stages. When the decomposition is complete the whole mixture is left till the next day, when the still liquid fatty acids are removed by a syphon to the washing vats.

To De Milly much of the present prosperity of the candle-making trade is due. He was the first to overcome the difficulty arising from crystallization of the stearic acid in the candles by adding a small quantity of wax, thus rendering the candles homogeneous; though of late years solid paraffin has been substituted for the wax, with even better results. To him also is due the idea of saponification by lime instead of soda (thus lowering the cost of the process very materially): also, the complete expression of the oleic acid by the horizontal hydraulic press, aided by heat: and lastly, the employment of boracic acid in the preparation of the wicks, the mode now universally in use to check the too rapid combustion of the cotton.

He has recently reduced the amount of lime used for the saponification. In place of 14 to 15 per cent.

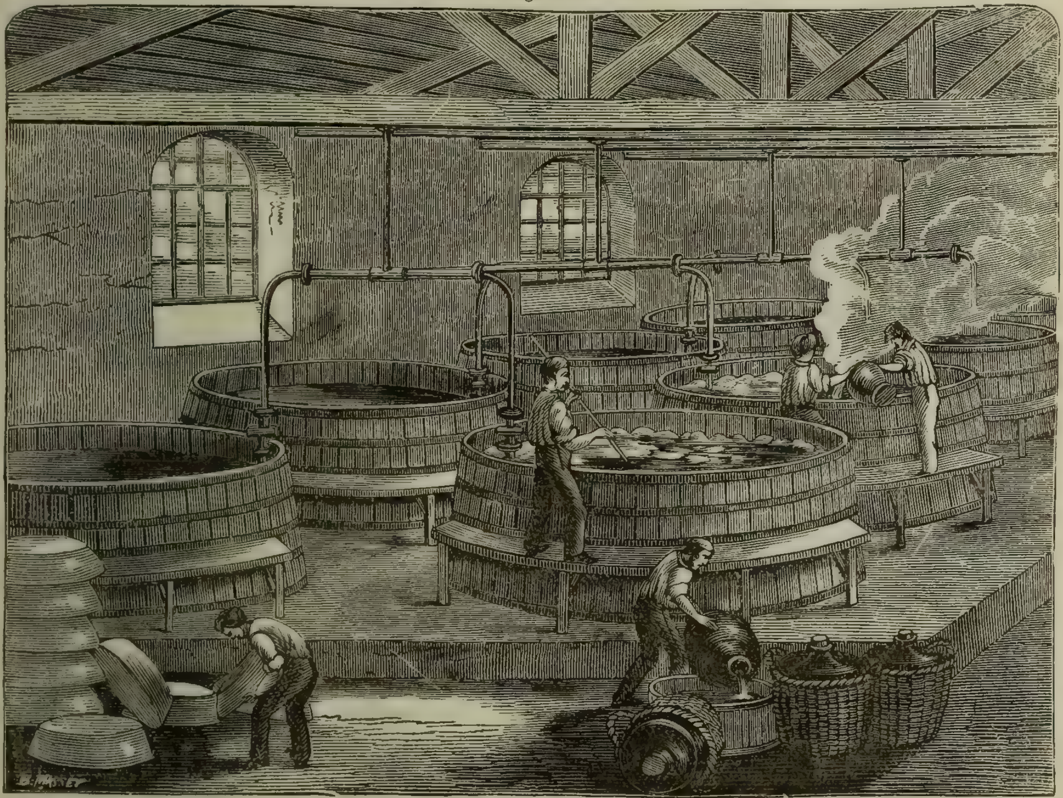
of lime, he now uses only from 2 to 4 per cent. This great reduction he effects by heating the milk of lime and fat to 341°·6 Fahr. (172° C.) by steam of 150 lbs. pressure, which has the temperature of 359°·6 Fahr. (182° C.)

Tallow treated in this way in a steam boiler with 2 per cent. of lime is completely saponified in seven hours. On withdrawing the contents of the boiler, the mixture is found to be an aqueous solution of glycerine, free fatty acids, and a small quantity of a lime soap. This method of saponification is very profitable, in consequence of so much less sulphuric acid being necessary for the decomposition of the lime soap. The lime soap is also much more easy to deal with on account of its comparative fluidity, since it can be at once run off into the decomposing vat.

Several explanations have been given of this mode of working; the most reasonable appears to be that of WRIGHT and FOUCHÉ, who show that water is by itself at a high temperature capable of causing the dissociation of fats and oils into glycerine and fatty acids. A process which was long successfully in use (TILGHMANN'S), in which the use of lime was entirely dispensed with, depended on this fact.

SULPHURIC ACID PROCESS.—In 1777 ACHARD discovered that neutral fats were decomposed by concentrated sulphuric acid. In 1821, when the true nature of fats was shown by CHEVREUL, CAVENTON drew attention to ACHARD'S experiments, pointing out the analogy between the action of sulphuric acid and the alkalies on fatty bodies. The fatty acids set free by the sulphuric acid are, however, mixed with carbonaceous matter which cannot be separated by chemical means. It has, however, been found, that if the black mixture is submitted to distillation with the help of a jet of steam, the fatty acids are carried over by the aqueous vapours, and stearic, palmitic, and oleic acids, together with glycerin, are obtained in the condenser free from colour and almost inodorous.

Fig. 7.



GEORGE GWYNNE, in 1840, patented a process for the manufacture of stearic acid by treatment with sulphuric acid and subsequent distillation by means of a vacuum pan similar to that used in sugar refining.

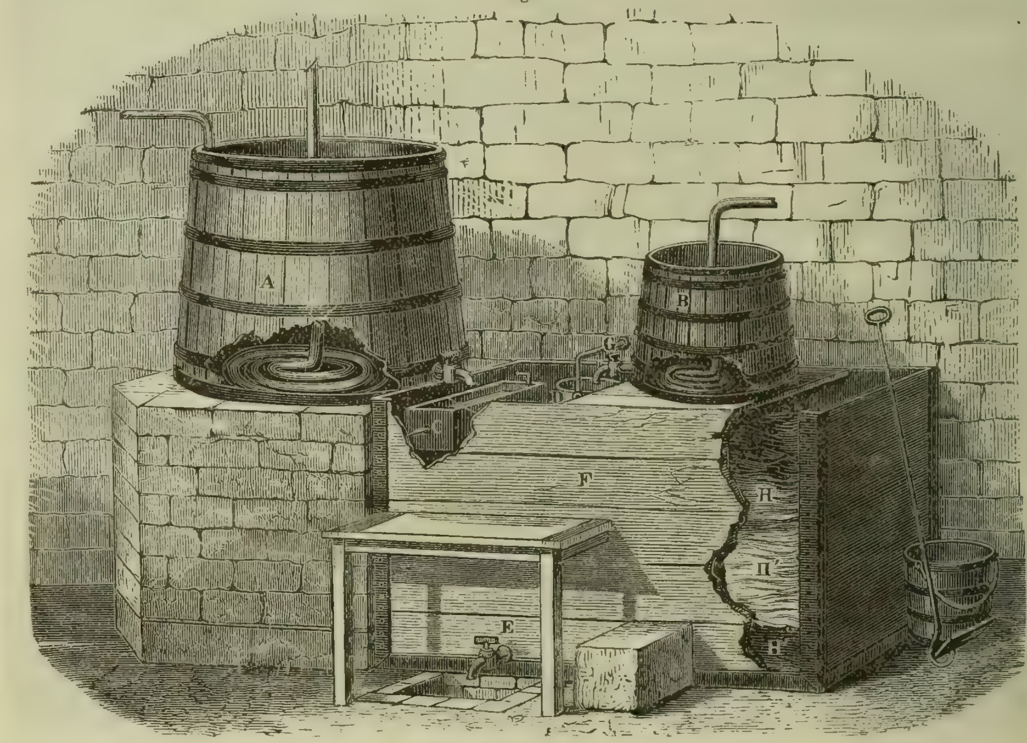
In 1841 DUBRUNFAUT really solved the question of distillation by assisting the volatilization of the fatty acids by means of a current of steam rushing through the black quagma. He, however, omitted the previous reaction with sulphuric acid, which is essential to success.

In 1842 PRICE & Co. (really Messrs. JONES & WILSON) took out a patent for the distillation of fats previously acted on by sulphuric acid or by nitrous gases. In a lecture to the Society of Arts Mr. G. F. WILSON says:—" While JONES and I were experimenting under this patent in one part of our works, Mr. GEORGE GWYNNE was at work in another, with a small silver retort connected with an air pump. His object was our carrying out on a large scale his patent of 1840; but finding that steam excluded the air as effectually as the air pump, we combined our forces, and in 1843 took out two patents for improvements in the processes and apparatus, under which part of our manufacture is still carried on."

The sulphuric acid process is available for palm oil, cocoa-nut oil, bone and marrow fat, kitchen stuff; indeed, the solid fatty acids of almost any kind of fat can be profitably extracted by this mode of working, or one of its modifications.

Fig. 8 represents a form of apparatus which is sometimes used. A is a wooden vat, lined with lead, and containing the sulphuric acid, which is maintained at the temperature of 194° Fahr. (90° C.), by a steam coil. B is a lead-lined vat, containing the fat to be operated on, which is likewise kept at the temperature of 194° Fahr. (90° C.), by a steam coil. The tank, F, in which the reaction is completed, is placed beneath the melting vat, B. The workman commences by filling the vessel, D, from the reservoir, B, with a known weight, say 1 cwt., of melted fat, by opening the tap, G, and the leaden trough, C, with the same weight of sulphuric acid (30 p. 100), by opening the tap of the acid reservoir. He then empties the vessel, D, into the trough, C, and agitates the whole rapidly by means of a rake: A brisk reaction takes place, and the mixture becomes black. At the end of about a minute the trough, which is suspended on an axle, is turned over, and throws the acid and fat into the tank, F, which is full of water, kept boiling by a steam jet. The sulpho-fatty acids are quickly decomposed by the boiling water into free acids and glycerin.

Fig. 8.



After a time the liquid separates into two layers. The lower, H', is water charged with sulphuric acid and glycerin; the upper, H, consists of stearic, palmitic, and oleic acids. The acid water and glycerine is first drawn off by the tap, E, placed at a convenient height, and then the fatty acids are run into another vat and thoroughly washed with hot water.

The fatty acids are still black and charged with many impurities from the foreign matters contained in the fats. The carbon and the impurities are alike removed by distillation.

Great advantage is gained in point of time by superheating the steam before passing it into the still, that is to say, by raising its temperature to about 482° Fahr. (250° C.), in place of 212° Fahr. (100° C.). This is effected by carrying the steam through coiled pipes heated in a suitable furnace. Fig. 9 represents the arrangement of the plant. B is a copper still containing the fatty acids; it is closed in by a dome provided with a man-hole, C. The supply of fatty acids is kept hot in the reservoir, A, placed above the furnace, H; they run into the still, B, through the tube, D D, on the tap, S, being opened. The still is kept hot by the fire, and also by being closed in at the top by a bed of sand in an earthenware pan which acts as an exterior lid. The still is provided with a thermometer, the stem of which projects outside it. As soon as this indicates the temperature of 482° Fahr. (250° C.), steam is admitted by opening the tap, R. Care must be taken that the temperature of the steam is 482° to 572° Fahr. (250° to 300° C.). The furnace, H, is used to heat a boiler, the steam from which is superheated by being made to pass through the heated coils, M and N; a thermometer is placed upon a bend of the steam pipe, near the tap, R. Under these conditions the fatty acids are volatilized in company, and carried forward with the superheated steam, and pass by the tube, E, into the receiver, G. This vessel (G) is a sort of first condenser. On opening the tap, L, with which it is provided, the first portions of the distillate are collected. These consist for the most part of sulphuric acid, acroleine, and like matters.

The vapours of the glycerin, and stearic, palmitic, and oleic acids, still mixed with steam, traverse the double coil, K (which is cooled by a continuous current of water passing through its exterior), are condensed and collected as liquids at the outlet of the tube, U. On flowing into the receiver the fatty acids rise, and are drawn off by the tap, V, whilst the water and glycerin go to the bottom, and are removed by the tap, X.

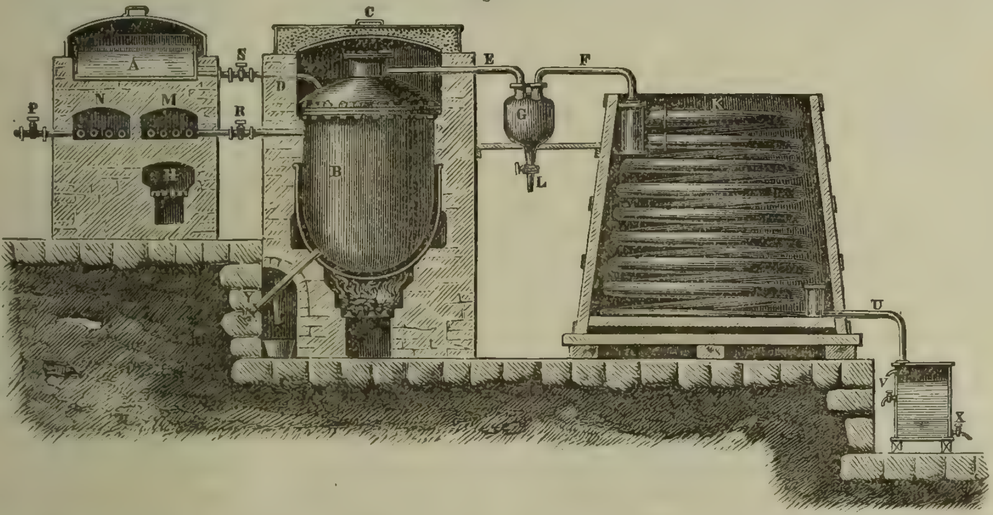
A brown fluid residue remains in the still; this is drawn off by a small pump, Y, at the lower part of the still. On cooling this residue concretes and becomes a hard black mass resembling asphalte. The residue of the distillation is 6 to 7 per cent. of the whole amount distilled.

The distillation occupies from twelve to fifteen hours, when the still is charged with 25 cwts. of sulpho-fatty acids.

The quantity of fatty acids obtained by this process are from palm oil 75 per cent., which on pressure yield 50 per cent. of solid stearic and palmitic acids. From tallow 60 per cent. of solid fatty acids are obtained. Saponification by lime only yields 45 per cent.

Palmitic Acid.—In the works of Price's Patent Candle Company palm oil is subjected to saponification and distillation to extract the palmitic and stearic acids by much the same process.

Fig. 9.



About 20 tons of palm oil are fused by steam in a large wooden vat lined with lead, and after it has settled this is pumped into an acidifying vessel, where it is heated by steam to about 350° Fahr. The steam is generated in the usual low pressure boiler, but the pipes through which it passes to the acidifying vessel are heated in a furnace, and thus it acquires a higher temperature. Concentrated sulphuric acid, in the proportion of 6 lbs. to the cwt. of the oil taken, is now gradually added. This is done by means of a leaden pipe extending across the boiler or tank, perforated with holes at the sides at a distance of 6 inches. The acid thus introduced equally over the mass causes violent ebullition throughout, by which the sulphuric acid and the palm oil are intimately mixed, even before any signs of decomposition are manifest. After a further heating of the mixture for an hour or more, it is allowed to rest for six hours. It is now of a blackish colour, and is pumped out to a vessel containing water slightly acidulated with sulphuric acid, and heated by blowing steam through it for two hours; it is then left at rest for twenty-four hours longer, after which time the water is removed. Both these vessels are well covered, and the vapours given off from them during the boiling are conducted by an exit pipe into the chimney.

After washing the fat, it is melted and raised by pumps to a tank commanding the stills; the latter are made of copper, and heated partly by an open grate fire, and partly by steam. A charge of the decomposed and washed fat, consisting of about 5 tons, is introduced into these vessels, and heat applied till it reaches about 560° Fahr., when low-pressure steam, raised to a higher degree of heat, is conducted into the mass, the air being excluded all the time. In order that the whole of the inclosed materials may be heated equally and regularly, the steam issues from numerous holes in a pipe convoluted on the bottom of the still, not unlike that of a sugar-house vacuum pan; and in this way the volatile constituents are more readily carried off to the condenser, together with the steam. The mixed vapours from the fatty acids and water are conducted to a series of vertical pipes, the temperature of which exceeds 212° Fahr., and in passing through them the fatty matter is almost wholly condensed, while the steam flows off to a refrigerator, where it meets with a current of cold water, and is condensed, together with any minute portions of the fatty acids that might have escaped. These are collected in a tank, whence the water is drawn off at the bottom, while the fat floating on the surface remains.

After a considerable portion of the charge has been driven over, the residuary matter in the still is drawn off, and introduced into iron pipes raised to a higher degree than the still, by being placed in a furnace; a jet of superheated steam is passed over it, by which the fatty acids are carried forward, atmospheric air being still excluded. By these means an additional quantity of fatty matters is obtained, while the substance remaining in the pipes, after the distillation is exhausted, is applied to the same uses as ordinary pitch.

The mixed fatty acids proceeding from these dis-distillations solidifies into a tolerably compact mass, and is used to a large extent for making the "composite" candles without being pressed; but these are nevertheless much inferior in melting point and durability to those made from the purified material.

To prepare the distilled palmitic and stearic acids for pressing, they are cut into shreds of a convenient size by a revolving cutter worked by an endless strap attached to a shaft from the steam-engine. The pieces lopped off at each revolution are conducted by a sliding tube to a carriage, where the slices as they fall are spread by the workmen upon cocoa-fibre mats in layers of equal thickness, regulated by an iron frame. Each layer of material is covered with another mat, and when the pile has become sufficiently large, it is carried off to the pressing-room. After the greater part of the oleic acid has been extracted, the cakes, after fusion and granulation, as before explained, are further expressed in horizontal hot-presses (see page 438), kept at a temperature of 85° or 90° Fahr. by means of steam.

After the pressing has been performed, the mattings are removed from the layers of fatty acids; these are divested of the yet oleaginous edges by paring, and are then brought to the steaming or boiling house, where they undergo another fusion with water acidulated with sulphuric acid, in large wooden iron-bound tuns, heated by steam pipes branching into them from a main connected with the steam boiler. Having been kept seething for some time, the whole is allowed to repose, and the acid water, after subsidence, drawn off; the fat is then washed with fresh quantities of hot water to remove all extraneous matter, and when this is accomplished, it is run into moulds or blocks. The material is at this stage sufficiently pure and hard to be manufactured into candles.

Manufacture of Candle Wicks.—The wick of tallow candles is formed of fine threads of cotton twisted, or otherwise bound together, though occasionally flax fibre and many other substances are employed, the former, however, answers best. For dip candles nothing answers so well as Turkish cotton rovings. The desirable qualities of wicks are, that they should burn freely and completely, leaving only a small quantity of a light ash, and must be good absorbents. The form of the wick varies according to the quality or composition of the candle; generally, they are composed of a number of threads, of greater or less fineness, twisted loosely or plaited together. No inequalities should exist, either in the shape of knots or adhering particles of cotton, as otherwise the candles would gutter. Again, the finer the threads composing the wicks, the more perfect will be the combustion of the melted fat.

For stearin and paraffin candles the wick is plaited over a braiding machine, and dipped in a solution of boracic acid before using. It thus twists out of the flame and is completely burnt away, so that snuffing is not required.

Some years back wicks which did not require snuffing were constructed by attaching to the plaits of cotton, by gimping, strings or threads of some fibrous material, with the intention that as the fat was consumed a bend should be given to the wick, which should carry its tip into the oxidizing part of the flame, and so insure its complete combustion. At the present time, by simply arranging the plait in such a way that one thread is shorter than the other the same effect is secured.

The wicks are then dried and soaked in a mixture, made by dissolving an ammoniacal or other alkaline borate, or nitrate of bismuth, in water. It has also been recommended to dip the wicks in a solution consisting of 3 quarts of water, 2 ounces of borax, 1 ounce of chloride of potassium, 1 of nitrate of potassium, and 1 of chloride of ammonium, taking care that they are thoroughly dried as well before as after the immersion. A solution of boracic acid is the dipping liquid now most used. The purpose in each case is to cause the fusion of the ash of the cotton and to retard the combustion.

To give a larger illuminating surface to the flame, some manufacturers use a double wick plaited, with the strands running from the centre upwards to the edges, and turning contrary ways, so that both ends will incline outward at the point of combustion, thus enlarging the extent of flame, and of course proportionally increasing the light.

The labour of preparing the wicks in large factories is considerably lessened by the use of machinery. Fig. 10 represents a plan of a machine for cutting and suspending the wicks for "dip" candles. Fig. 11 is a sectional elevation of the same: A A is the frame; B a grooved roller, over which the cords of twisted or plaited cotton are passed from the bobbins, J J; C is the clip or holder, seen in a front elevation in Fig. 12, and consists of two principal pieces or bars, *a* and *b*, held together by means of two sliding clamps, *c c*. D and E are the blades of the scissors; the former is fixed and the latter movable. F is a trough in which the liquid fat which is used as a cement to retain the wicks upon the rod, H, is contained. The fat is kept liquid by means of a jacket, which is surrounded by hot water, steam, or heated air. H is the square rod or "broach," upon which the wicks are fixed and supported during the time they are immersed in the frame resting upon the table G.

The following is the manner in which this apparatus is worked:—The cords being prepared on suitable bobbins are brought down through the roller, B, and secured between *a* and *b* of the clip or roller, C, each cord being left to project 1 inch in advance of the front edge of the clip. The bars, *a* and *b*, are made to lay firm hold of the cords by moving the clamps, *c c*, which bring them together in consequence of the wedge-shaped form of the upper bar, *a*. The cords being thus secured, the clip is lifted up and drawn forward by the workman, after which the free ends of the cotton that are left protruding from it are immersed in or brushed over with the fatty cement contained in F, and then laid on the top side of the square broach or suspending rod, H, and are made to adhere to it with sufficient firmness to sustain them during the process of dipping by a slight pressure. Next, the clip is slackened by moving the clamps, *c c*, outwards; they are then pushed forth over the cotton towards the bobbins till the length to be cut for the candle is gained, when, by reversing the movement of the clamps, *c c*, the cords are again tightly laid hold on; and finally the clip is rested upon the table, G, which is about 1 inch from the cutting apparatus. The movable blade, E, of the cutter is brought down, and the set of wicks of the proper length cut off, leaving as much of the cotton adhering to the end next the suspending rod as will support the next batch as before. The rod, H, with the wick adhering to it, is placed in a dipping frame, and another rod again loaded with wicks as before, and so on till the frame is full.

Fig. 10.

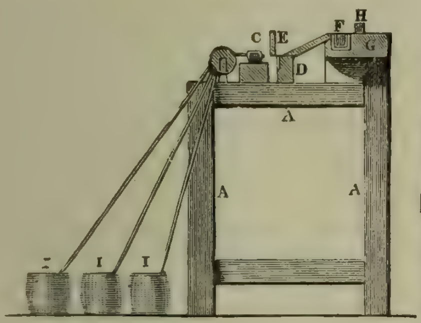
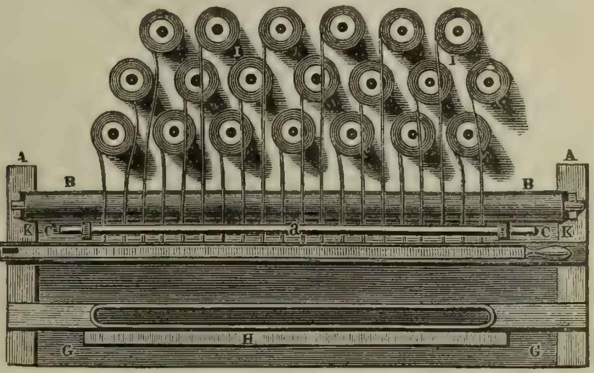


Fig. 11.



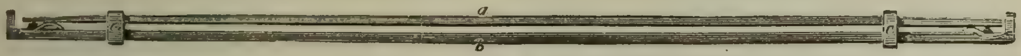


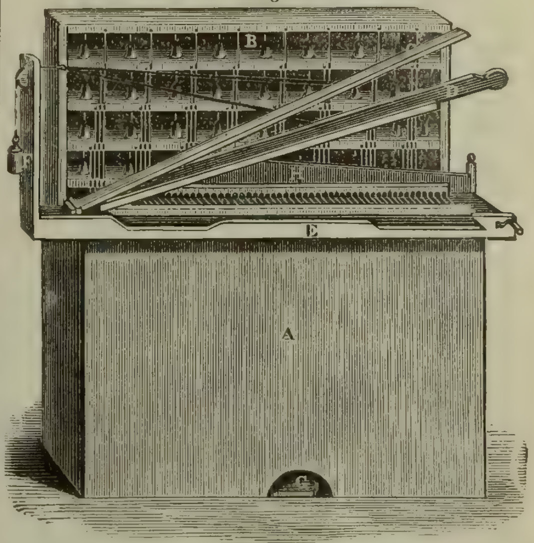
Fig. 12.

The bars of the clip, C, may be hinged, so that when opened they will allow the bundle of yarn or cotton to pass freely; but when closed they will take a firm hold of them, as shown in the cross section, Fig. 12.

Another machine in extensive use in America is the following. It is said to cut, spread, and twist as much wick in an hour, with the attendance of one man, as will suffice for 1000 lbs. of candles.

Fig. 13 is a drawing of the apparatus. A is the body of the machine, inclosing the pulleys and other appendages that regulate the movement of the carriage, B, which is set in operation by the treadle, G. The carriage, B, rests upon the body; it is a kind of framework running on wheels, and containing a number of boxes placed shelfwise, and serving as receptacles for balls of cotton wick, the ends of which run through a notched reed, below H; it comes forward upon the twisting board, E, at the back of which a knife, H, is fastened, that serves as

Fig 13.



the under blade of the clipper, D. This, when drawn down vertically, severs the wicks evenly. The twisting-box, E C, consists of two boards hinged, and moving on rollers. A turn of the crank near the end communicates the motion which twists the wicks after they have been cut by the knife, D, and this knife having effected its purpose is immediately drawn up by a counterpoise, F. At the front of the twisting-box, D, a sliding-box is so fixed that it can be graduated to regulate the required length of the wicks. Motion being communicated to the machine, the yarn is then cut, spread, and arranged on the rods simultaneously, and in complete readiness for dipping: as soon as the workman removes it another rod rolls into its place, and thus the work proceeds till the wick or rods are expended, when, as a matter of course, a fresh supply must be provided.

Fig. 14.

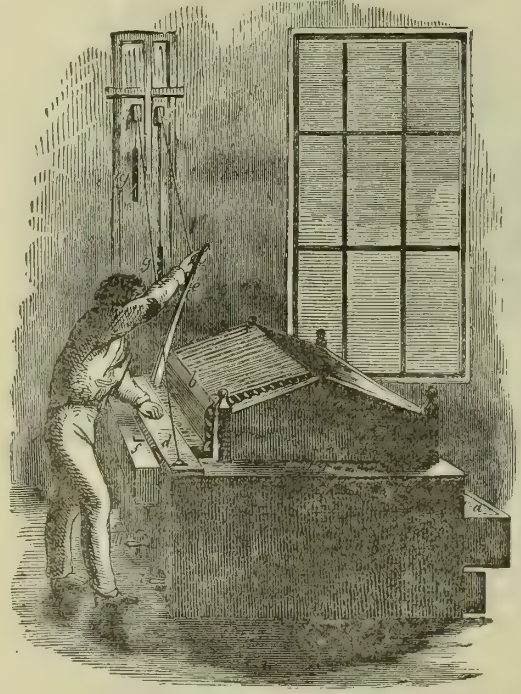


Fig. 15.

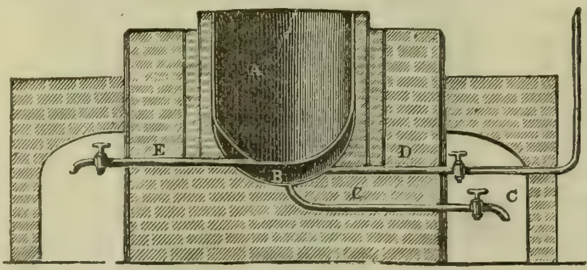


Fig. 14 shows another machine for cutting the wicks; *a* is a box in which the balls of cotton are placed. The ends of the wicks are drawn over the bridge, *b*, above which the rods, *c c*, are introduced, and as the workman fills each rod he brings others forward by means of the treadles, *h i*; *d* is a hand-board which keeps the wicks in their place while they are being cut by the knife, *e*. Both knife and board are lifted up, after the wicks are cut, by counterpoises, *g g*, attached to them by cords passing over small pulleys. The length of the wick is regulated by the screw, *f*, in front of the workman.

Dip Candles.—Candles are made either by "dipping" or "moulding." In the former process the prepared wicks are repeatedly immersed in a bath of melted tallow, till a sufficient quantity has adhered to them: the finished candles are known as "dips;" and in the latter, the wicks are placed in pewter moulds, and the melted fat poured in and allowed to cool; in this case they are termed "moulds," or moulded candles.

It may be here mentioned that in this country, at any rate, the manufacture of dip candles is rapidly dying out. "Dips" are invariably made of tallow.

The tallow is clarified by remelting it with about 5 per cent. of water in a copper pan, fitted with a steam-jacket (Fig. 15).

A represents the copper pan inclosed in a jacket, B, and supported on brickwork or masonry. A stopcocked pipe, E, opens into the bottom of A, and two others, C and D, communicate with the interior of the lesser one at the bottom and side. Into the vacant space between the walls of the tanks, steam is injected through the pipe, D, which is furnished with a stopcock for turning it off when desirable; the jacket should be supplied with a steam-gauge to notify the pressure of steam upon it.

Instead of this arrangement the pan may have a jacket carried completely to the top, be supported on a pedestal of brickwork, and be surrounded with a felt casing, to hinder dissipation of heat by radiation.

In Fig. 16, P is the copper-melting vessel surrounded by a jacket J (which may be of iron), outside which is a casing of felt, F, the steam (5 lbs. pressure is sufficient), enters at S, and is carried by a copper coil, C C C, round the pan to the bottom of the jacket, where it passes into the jacket itself, G is the steam-gauge, T the tap for drawing off the tallow, and W, that for the condensed water. Before turning on the steam the small tap, E, must be opened to allow the air to escape; it is closed when the jacket is filled with steam.

The fat, after being minced, is thrown into the pan, with some water, and the whole is melted by the circulating steam. When sufficiently fluid, it is drawn off into another vessel, where, after it has settled, the superior fat is drawn off from above the water into another tank, and the residuary matter expressed. Frequently the casks of tallow, after being unheaded, are inverted over the pan, and emptied into it by directing a jet of steam into them.

A little indigo ground in oil is sometimes added to neutralize the yellow cast of the tallow; and instead of water, lime or solution of alum, ammonium chloride, saltpetre, and other salts, are used by some melters. By adding 7 parts of sugar of lead, dissolved in a little water, to each 1000 parts of tallow, and agitating thoroughly, the tallow is made much harder.

The mode of making dips is very simple. The tallow is poured into a trough made of stout walnut or cherry boards firmly put together and resting on a pedestal or other support 2 feet high; this trough is lined with lead, and on the side on which the workman stands is a thick board, the same length as the trough, fixed in a slanting position, to tap the candles on, and thus to detach the superfluous tallow from their ends.

By the side of the dipping trough, and to the left of the workman, is the reservoir of melted fat—*c c*, Fig. 17—kept properly fluid by a steam jacket; or the same may be effected by renewing the hot tallow at regular intervals. On the right hand is fixed a long upright side frame, under which is a tray, made of boards, which may be lined with lead, of the same size as the frame, and with its sides inclined outwards, to collect the droppings which fall from the wicks on their removal from the bath. Above the bath is a beam to which the workman, when the rods of candles become too heavy for him, attaches them, at the same time balancing them by the metallic slide on the lever end of the beam—the dipping is thus facilitated. This arrangement is shown in Fig. 17.

Thin wooden rods about 2½ feet long are fitted with wicks, ten on each rod.

Having supplied all the rods with wicks, the workman brings them to the frame at the back of the trough, and the dipper takes six or eight at a time upon the small frame, *c*, which he holds in his hand, shown in the annexed Fig. 17, and by an expert movement introduces the dry wicks into the molten tallow, *a*; when they are completely saturated he withdraws them, and by a dexterous shake, whilst the ends of the wicks are yet in the fluid, separates any which may have stuck together.

To facilitate this operation, the tallow is brought into a more fluid state than at subsequent dippings. When the wicks are charged with the tallow, they are laid on a longitudinal frame to the right of the operator, and fresh rods are proceeded with in the same way, till the whole of the wicks are immersed, the bath being kept full of melted tallow during the time.

The second dipping is performed in the same way as the first, except that it takes less time; the bath of tallow is also colder, in order that more tallow may be taken up by the wicks. It is held to be of a proper consistency when the tallow in contact with the sides of the trough is observed to solidify. In this and the several succeeding dippings, it is necessary to retain the lower part of the candle a little longer in the melted tallow than the upper, to prevent the bottom of the candles being too thick. The ends of the candles should be tapped upon the board, *b*, on their withdrawal from the bath, to detach the small pellicle that drops down, but which solidifies before it falls. After several dippings the candles become heavy, and the frame, which hitherto has been held in the hand, is hooked upon the beam, *d*, and counterpoised with the weight the candles

Fig. 16.

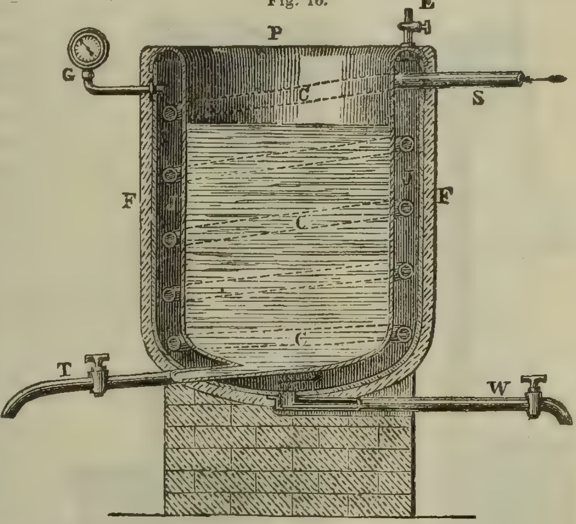
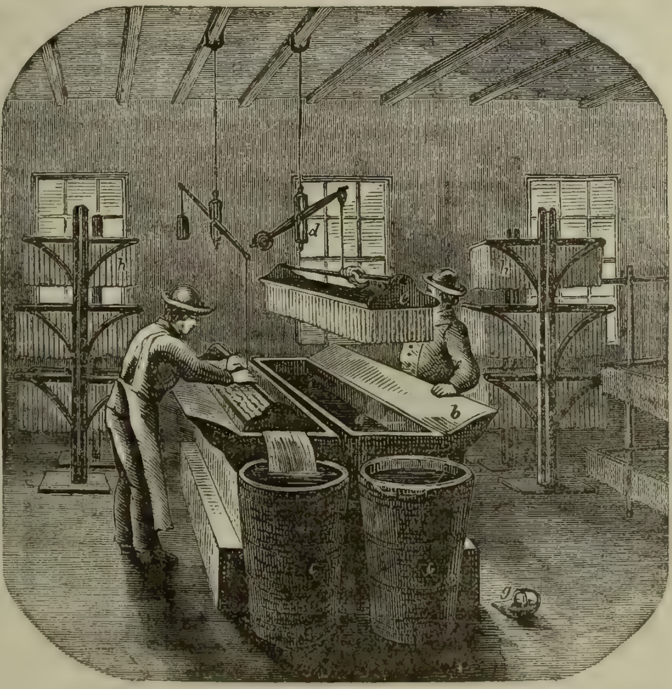


Fig. 17.



are desired to have when finished. The final dippings must be performed with care and skill, to communicate a proper cylindrical smooth appearance. The conical spire at the top of the candles is given by dipping a little deeper at the last dip. If the precaution of tapping the ends of the candles on the board, as they are raised each time out of the trough, be imperfectly executed, the fat will extend half an inch or more below the wicks, and the tallow thus accumulated become a waste to the consumer. If this should happen the rod of candles is held over a heated metal trough until the superfluous fat is removed.

Fig. 18.

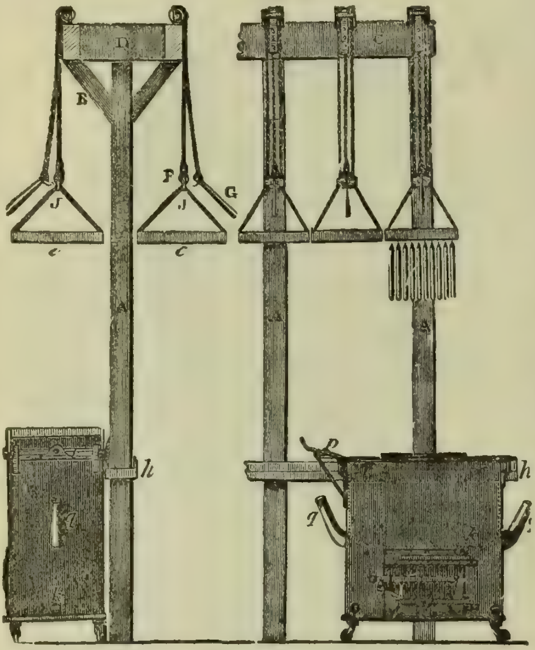
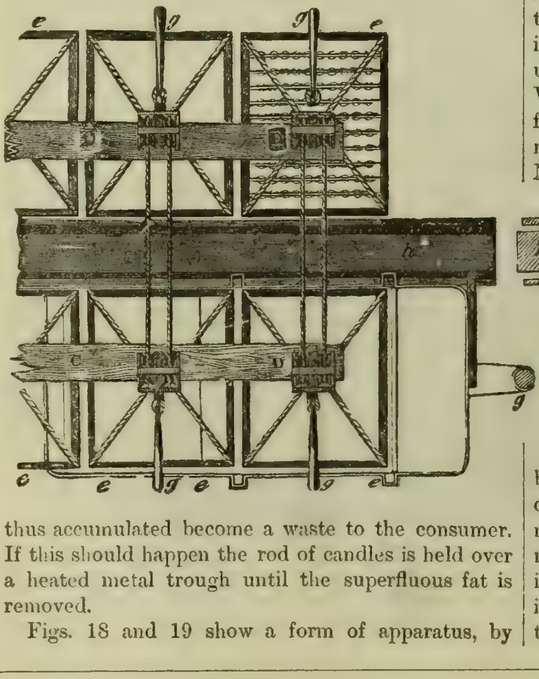


Fig. 19.

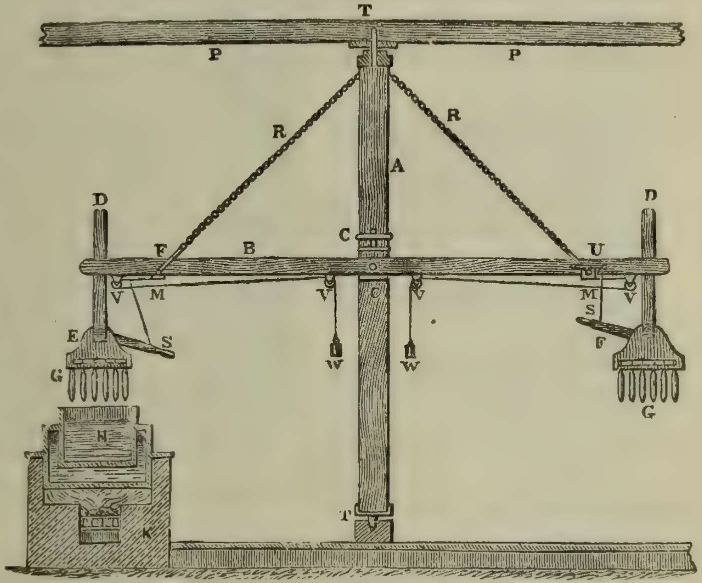


Figs. 18 and 19 show a form of apparatus, by which many candles can be dipped in succession with ease and regularity. The frame consists of five oak-wood beams, A, each bearing near its top two abutments, B (seen in the end view, Fig. 18), connected together by the long cross pieces of horizontal frame, C, throughout the length of which are five small traverses, wherein the beams or posts, A, of the frame are mortised. The iron caps, D, are fixed upon the sides of the long cross pieces of the frame, C, and each has two brass pulleys. The fastening or connection of these caps is effected by stout screws inserted in the beam, C. Each pulley receives a cord, F, at the extremity of which is a small wooden frame of a rectangular form, and grooved at the sides interiorly, for the purpose of supporting the broaches or rods on which the wicks are suspended. The wooden handles, G, have each a hook fastened in a hole in the centre of a small rectangular iron plate, J, to which are attached the cords of the pulley and rectangular frame, *e*. The long traverse, or cross piece, *h*, is grooved on each side, to guide the movement of the furnace. This arrangement of the pulleys, and the guiding of the beam, *h*, are shown in the vertical view (Fig. 18), where the arm of the furnace fits into the grooving, along which it runs as the latter is pushed round the machine. The furnace moves on four castors. It has two doors for the purpose of introducing a small tray of red-hot coals, to keep the tallow at the right temperature for dipping. Dampers are used to regulate the combustion of the coals. There are two baths, one inserted in the other. The larger is filled with water and kept at a temperature of 85° to 95° Fahr., and by contact of the liquid heated to this degree the smaller bath of material will have acquired a temperature of 50° to 60° Fahr., and by this means the adhesion of the stuff is expedited. To catch the drippings from the candles, on being made to emerge from the bath, a plate is fixed to the exterior of the tank, inclining inwards, so that any of the fat that falls upon this plate is returned to the bath without waste. When this machine is worked the two receptacles for the tallow are filled, and then heated to the necessary temperature by the fire beneath them. Next, the furnace is pushed forward under the frame *e*, on which the rods, loaded with the wicks, are supported; this frame is depressed by the hand, and the wicks immersed repeatedly in the fat till the candles have become sufficiently large, and then the frame is raised to a higher elevation, and so retained by hooking the handle, G, to the plate, J, as before described.

The furnace is then removed to the next frame, and the dipping proceeded with as before, and so on till the frames are worked off.

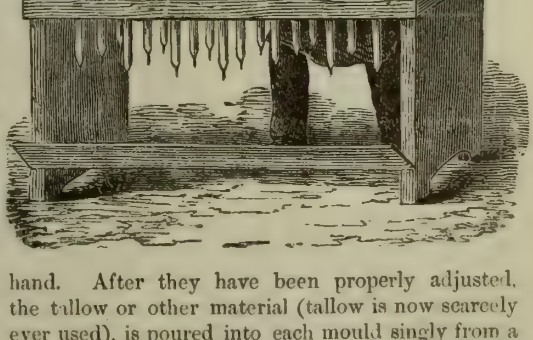
The candle-dipping machine, known as the Edinburgh wheel, is exceedingly convenient to use, as it can be worked by one man. Fig. 20 shows the machine as it stands in the middle of the dipping-room. A A is a strong upright post turning upon iron axes, which are inserted into the socket T and into the beam P P. It is thus free to rotate. Near the middle of the upright A six mortises are cut at small distances from one another, and crossing each other at an angle of 60°; into each of these mortises is inserted a long bar of wood, B, which moves vertically upon an iron pin, C, passing through the middle of the shaft. The whole presents the appearance of a large horizontal wheel with twelve arms, of which, however, only two are seen in the figure. From the extremity of each arm is suspended a frame, E (or *port*, as the workmen call it), containing six rods, on each of which are hung eighteen wicks, making the whole number upon the wheel 1296. The machine, though apparently heavy, turns round by the smallest effort of the workman, and each "port" as it comes in succession over the dipping mould, H, which is placed in a water bath mounted on the furnace, K, is gently pressed downwards by the handle, S; by these means the wicks are regularly immersed in the melted tallow. As the arms of the levers are all of the same length, and as each is loaded with nearly the same weight, it is obvious that they will all naturally assume a horizontal position. In order, however, to prevent any oscillation in the machine in turning round, the levers are kept in a horizontal position by means of small chains, R R, one end of which is fixed to the end of the top of the upright shaft, and the other terminates in a small square piece of wood, M, which exactly fills the notch, F, in the lever. As one end of the levers must be depressed at each dip, the square piece of wood is thrown out of the notch by the workman pressing down the handle, S, which communicates with a small lever inserted into a groove in the bar, B. In order that the square piece of wood, M, fixed in the extremity of the chain may recover its position upon the workman's raising the port, a small cord regulated by the weight, W, is attached to it, which passes over the pulley, V, and again over the second pulley, V, and draws the block, M, forward to the notch. In this way the operation of dipping may be conducted by a single workman with perfect ease and regularity. No time is lost, and no unnecessary labour is expended in removing the ports after each dip; and the process of cooling is much accelerated by the candles being kept in constant motion through the air. The number of revolutions which the wheel must make in order to complete one operation, must obviously depend upon the state of the weather and the size of the candles; but in moderately cold weather, not more than two hours are necessary for a single person to finish one wheel of candles of a common size. Upon the supposition that six wheels are completed in one day, no less a number than 7776 candles will be manufactured in that space of time by one workman.

Fig. 20.



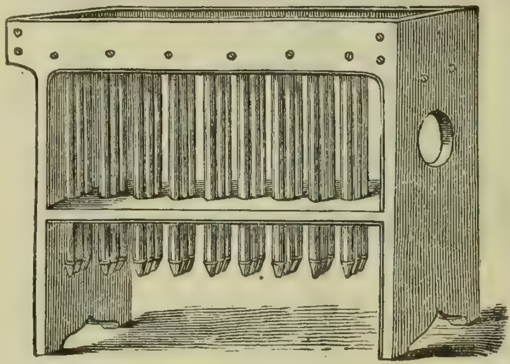
Mould Candles.—Moulding is a simpler and more expeditious method of making candles than dipping. Pewter moulds of the shape of the annexed figures are usually employed.

Fig. 21.



They are arranged in a frame made of four solid pieces of hardwood; the top is sometimes an iron plate, in any case it is perforated with holes corresponding to the size of the moulds, and surrounded by a ledge to prevent any loss of material from accidental overflow. The wicks are inserted by hand. After they have been properly adjusted, the tallow or other material (tallow is now scarcely ever used), is poured into each mould singly from a can (Fig. 21), or it may be poured upon the board, and then the whole of the moulds are filled at the same time. In the latter instance, the rim around the top is provided with a movable flange to facilitate removal of surplus fat, and the moulds are placed closer together (Fig. 22). The frame is then either left at rest, or removed to a cool place till the melted fat solidifies, after which the candles are drawn out.

Fig 22.



Figs. 23 and 24 show a common form of mould. The pewter of which it is made is generally an alloy of 2 parts of lead with 1 of tin. The body of the mould is proportioned to the size of the candle, and is slightly conical. Its lower end, c, is shaped so as to form the top of the candle, and is perforated in the centre, in order that the wick may pass through; the upper part or base has a narrow flange, a b, which supports it upon the top part of the frame. The disc, d, is for the purpose of insuring that the wick is in the centre of the mould. The mould itself is dropped into a hole cut for it in the top of the frame. c is a spigot or plug to fasten the wick before it is drawn tight.

Fig. 23.

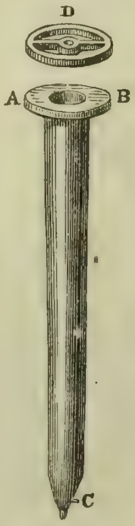
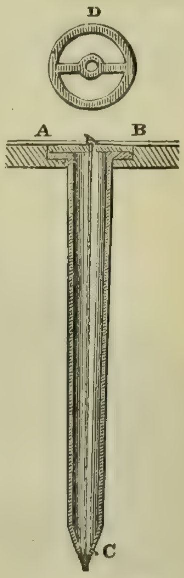


Fig. 24.



Some candle-makers support the wicks by a series of horizontal wires passed along through the loops of the wicks.

The manner of wicking the moulds is as follows:—A strong wire needle, bent into a catch or hook at one end, and turned into a ring at the other, for facility in handling it, is employed for this purpose. The workman lays the frame horizontally on a table, and taking a number of the prepared wicks in his left hand, he inserts, with the right, the small hooked end of the wire at the lower end of each mould, and as soon as it appears at the mouth lays hold with it of the looped end of the wick, and then withdrawing the wire carries the wick through. The wick, at the mouth of the cylinder, is secured by passing a wire through the loops over each range of moulds. When the whole batch is in this way completed, the frame is restored to its original position, the wicks being first stretched tightly, and fastened by means of a small spigot, or wooden plug, introduced at the lower part.

The moulds used for the manufacture of tallow candles were formerly made of iron and brass. The first substance is now rarely employed; the next is too readily acted upon by the acidity which is liable to prevail in the tallow, and which would destroy the moulds made of it. Pewter is now always used for tallow; but for stearine candle-moulds, instead of pewter, pure tin or a mixture of tin and antimony is used, partly on account of the smutty colour communicated to the candles by pewter moulds, and partly because of the difficulty experienced in drawing them out. In choosing moulds preference should be given to those which are hard and well burnished interiorly. Care also should be taken that the burnishing has been effected by a vertical motion, instead of a rotatory one, as this obviates many inequalities in the mould which would be transferred to the candles. It is also to be observed that, when the moulds are thin, the liquid fat solidifies much quicker than when a large mass of metal surrounds it.

The moulds are filled by running tallow into them, or into the trough in which they are set, from a cistern of melted material, which is kept full by constant supplies from an adjacent vat. When the workman sees that the moulds are half-full he looks to see that all the wicks are tight; he then fills them up. The workman discovers when the candles have set sufficiently to allow of their removal, by a peculiar snapping noise emitted by them when he presses his thumb against the bottom of the moulds. He then withdraws the small wires or spigots which keep the wicks tight, and scrapes off the loose fat from the tops of the moulds with a wooden spade. He next introduces a bodkin into the loop of the wick, and draws each candle out of the mould.

Stearine Candles.—The wicks for stearic acid candles, as before remarked, require special preparation. Pure cotton would absorb too much fat, and burn too quickly; also to keep the proportion of wick to melted matter constant, it is necessary to adopt some contrivance for turning the top of the wick outside the flame, so that coming in contact

CANDLE.

COWLES' CANDLE MOULDING MACHINE.

Fig. 1.

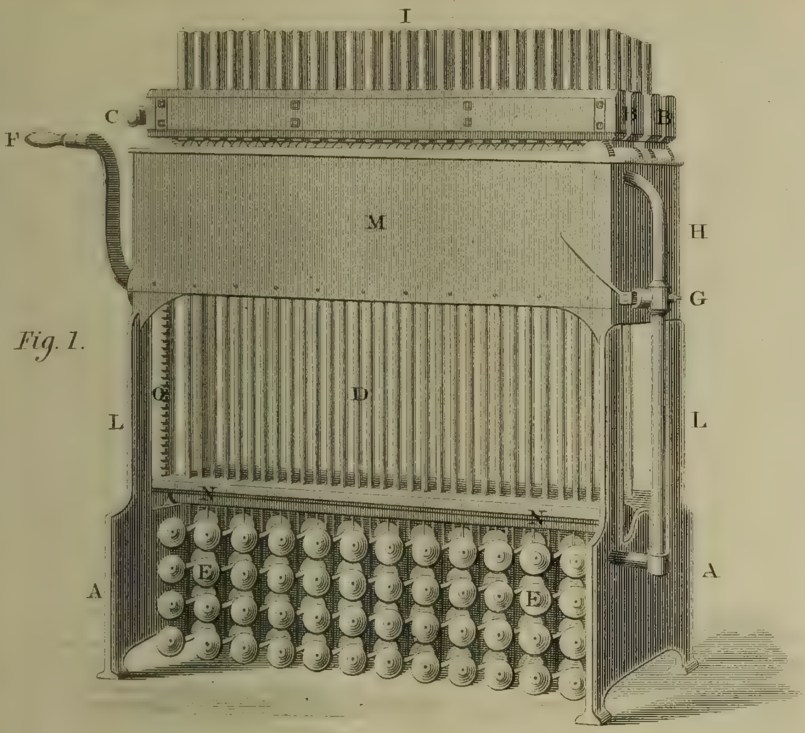


Fig. 3.

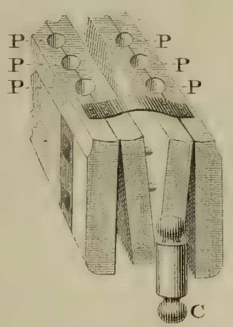


Fig. 4.

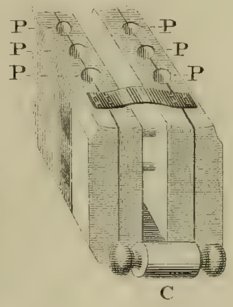


Fig. 2.

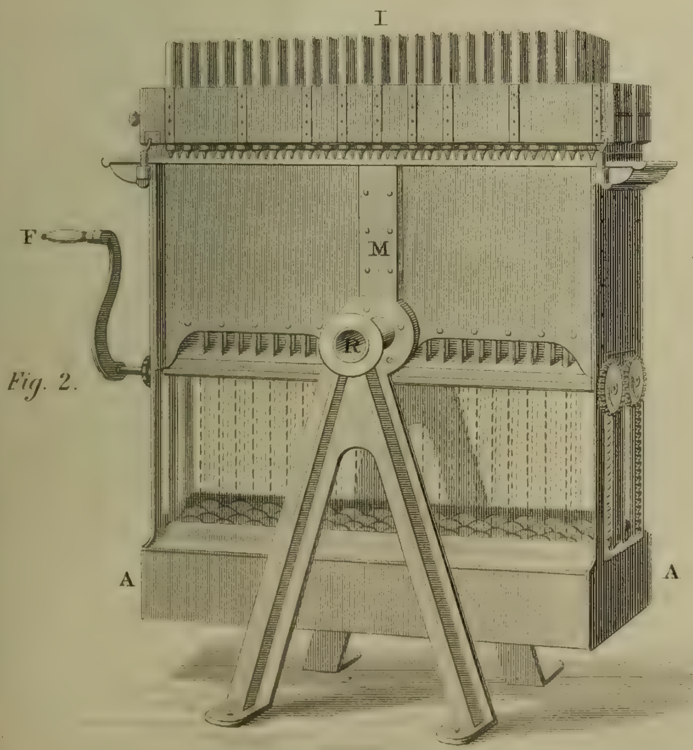


Fig. 6

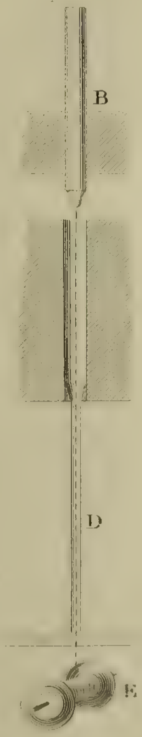
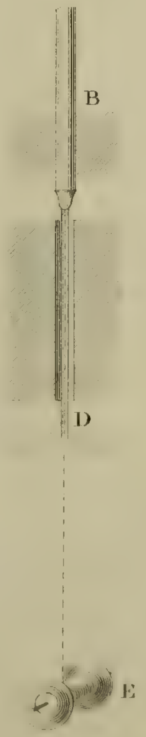


Fig. 5.

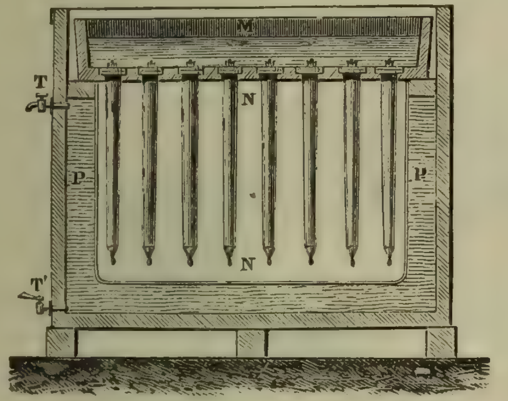


J. B. LIPPINCOTT & CO. PHILADELPHIA

with the air outside the blue envelope of the flame (its very hottest part), it may be reduced completely to ash. This is managed by so plaiting the wick that a twist is given to it, which, as it becomes unplaited in burning, causes it to turn outwards. The substances used to prevent too rapid absorption are now made to assist in regulating the length of the wick. The wick is composed of three threads; one thread being shorter, and thus having a greater strain upon it than the others, gives a curvature to the whole plait as soon as the melting of the candle allows it to have free play.

Payen recommends a solution of from $\frac{3}{4}$ to $1\frac{1}{4}$ ounces of boracic acid in a gallon of water, to which a few drops of sulphuric acid has been added. In Austria solution of phosphate of ammonia is used as a pickle. Addition of a little alcohol will insure perfect wetting of the wicks. Dr. Bolley recommends a solution of sal-ammoniac at 2° to 3° B. The wicks, after being soaked in one of the above solutions for three or four hours, are wrung out (a centrifugal machine is usually employed), and then dried in a steam-heated iron-jacketed box.

Fig. 25.



In making stearine candles great care must be taken to avoid crystallization of the stearic acid. 2 to 6 per cent. of white wax, or what is still better, 10 to 20 per cent. of paraffin, is added to the melted stearic acid, and the whole thoroughly mixed by constant stirring. When the mixture of fats has become so cold as to look milky, it is ready for candle making.

The moulds must previously be heated to prevent too sudden cooling of the stearine. Fig. 25 is the hand moulding box used in French candle works; N N is a tin or sheet-iron box in which the moulds are placed. This box is surrounded by a jacket, P P, which is heated to the temperature of 212° Fahr. (100° C.) by a current of steam. The tap, T, is to allow the air to escape on first turning on the steam, the lower tap, T', to let out the water produced by condensation. The vessel, M, acts as a funnel to the moulds. A sufficient amount of stearine is poured in to cover the tops of the moulds. As soon as the moulds are heated to 113° Fahr. (45° C.), the stearine is poured in, and the box, M, N N, is then removed from the steam jacket. When the moulds are quite cold the candles are extracted from them by lifting the surplus stearine which has been poured into M, and to which they are attached.

Moulding by hand is now only in use in small factories. Candle machines, for the purpose of saving time and labour in what by hand is a very tedious operation, are very numerous. The machine now almost universally used is an American invention, many improvements upon which have been patented in this country.

The candle-moulding machines, as made by E. Cowles, are shown in Candle, Plate I., Figs. 1 and 2 (the letters denote the same parts). A A is the iron frame of the machine, with standards, L L, supporting a water jacket, M, through which the candle moulds run. The top of the jacket is somewhat sunk, so as to form a shallow tray (Fig. 2). This is perforated at regular intervals to receive the moulds, which are simple pewter tubes open at both ends. The bottom of each mould is formed by a close-fitting inverted cone, with a hole in its centre for the wick to pass through. These cones, technically called "tips," give shape to the top of the candles: they are sometimes embossed with the maker's name. Each tip is fixed on the top of a hollow rod, which has its lower end fastened to the board, N N. These rods are seen at D. The board, N N, with the attached rods, is raised by the rack-work, O, when its corresponding cog-wheel is turned by the handle, F. The bottom of the machine contains bobbins of wick, E, which revolve on stout iron pins. Each mould has its own spool of wick.

At the top of the machine are two racks, B B, furnished with holes, P P, precisely opposite the moulds beneath, to receive the candles. These racks are hinged at the top. Fig. 3 shows one of them open; Fig. 4 one closed. Each candle is pushed up into its respective orifice, and there secured by turning the handle, C, of an eccentric wedge, which runs the whole length of the rack and nips the two halves tightly together.

The moulds are heated and cooled by sending hot and cold water (or steam and cold water) alternately through the jacket, M. The inlet pipe is at the back of the machine, Fig. 1, and through the axle, R, of the tilting machine, Fig. 2. H is the overflow pipe, and G the valve for running off the water.

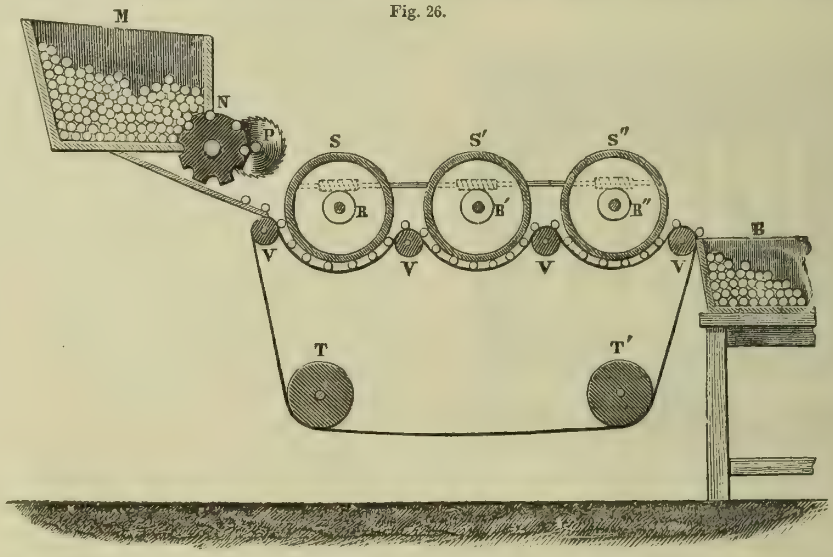
In working the machine, connection is made with the hot water or steam-pipe, and the cold water pipe and the outlet pipe seen to be clear of obstructions. The piston-rods, D (Fig. 1), are then raised by turning the crank handle, F, until the "tips" are level with the butt ends of the moulds in the tray. (During this time the racks, B, are not on the machine.) A cotton hook, or a doubled piece of thin wire, is next passed through the "tips" and hollow rods to which they are fixed, until it appears below the board, N. The wick on one of the bobbins, E, is then passed through the bend of the wire, drawn up through the candle mould, and secured in any convenient way. This operation is repeated till all the moulds are "cottoned;" upon which the board with the attached "pistons" is lowered by reversing the crank, F The moulds are next brought to the desired temperature by hot water or steam, and the melted stearine or paraffin poured into the tray. As soon as the moulds are full, the hot water is run off from the jacket and cold turned on; as soon as the candles are set they are ready for removal. To effect this, the superflous fat is shaved off from their butts with a tin scoop or wooden spade, and the racks, B, B (open), placed in their proper places over the machine, and the handle, F, turned, so as to again raise the pistons on N, N. The candles are thus ejected into the open clamps, which are then closed by turning the handle, C. In Fig. 2 the piston-rods are represented as having just cleared the moulds of candles.

The pistons are now lowered; the "tips" again form the bottom of the candle moulds, in the exact centre of which the wicks, which have been dragged through the perforated tips and rods, are held by the candles, I. Melted material is again poured into the candle moulds, and when nearly set, the wicks at the butt ends of the candles are cut, and the racks, B B, removed, emptied, restored to their places, and the operation conducted as before.

The action of the machine can be seen by a glance at Figs. 5 and 6. The wick is stretched between the bobbins, E E, and the candles, B B; in Fig. 5 the hollow rod, D, with its conical tip, is in the act of ejecting the candle and unwinding the bobbin to supply a wick for the next filling; in Fig. 6 it has returned to its place, leaving the candle in the rack, and the wick stretched between the bobbin, E, and the candle, B The workman should see that the cotton under the piston plate is slightly strained.

Fig. 2 represents a machine for making candles with an inner core of softer material than the exterior. It differs from Fig. 1 in being movable on the axis, R, through which also the hot and cold water have ingress and egress. It is worked precisely as the machine just described, except that immediately the first pouring of the material has hardened round the sides of the mould, the machine is turned over on its side, upon which the fat runs off, leaving a hollow candle, which is then filled up with a fat of a lower melting point.

Fig. 26.



If the stearic acid candles are not sufficiently white, they are bleached by exposure to air and light. A framework is provided on which are stretched two lead-wire nets, the one about the height of half a candle above the other. The meshes of the upper net are wide enough to admit of a candle being passed through it, while the meshes of the lower one are narrower. The candles are placed one by one in these meshes vertically, the bases resting on the lower meshes, whilst the conical tips point upwards. In this position they are left for a week or a fortnight, according to the season of the year. The candles are thus to a certain extent bleached, and are also made to appear whiter than they really are by the gradual interposition of air between the crystalline particles of their mass, thus rendering them less transparent by destroying their refractive continuity.

After this exposure the candles are somewhat soiled by dust, &c. This is removed by washing them with a weak solution of carbonate of sodium: they are dried by mutual friction on a moving endless cloth, upon which they are thrown.

The exterior polish seen on the best kinds of stearine candles is given by special machinery. The candle polisher invented by M. Binet is very efficient. Fig. 26 represents it in section. The candles are piled horizontally in the box M. The wheel, N, brings them one by one against the circular saw, P, which pares off the excess of stearine from their bases. They then fall upon an endless woollen cloth, which is distended by the small wheels, V V V V, and the larger ones T T, and passes beneath the three drums, S S′ S″. During the circulation of the endless cloth the three large drums, S S′ S″, which are covered with felt or some similar material, are likewise moved in the same direction by the three pinions of the toothed wheels, $R\,R'\,R''$. By the time the candles arrive at the receiving-box, B, they are beautifully polished by the friction they have been subjected to between the two cloths.

PARAFFIN CANDLES.—(The manufacture of Paraffin will be fully described under that title in vol. ii.). FREDERICK FIELD, F.R.S., states that the credit of first manufacturing solid paraffin on anything like an extensive scale is due to Messrs. WILLIAM BROWN & Co., of Glasgow. A very eminent London firm, addressing the secretary of juries of the 1862 International Exhibition, says:—We have been using paraffin in the manufacture of candles since March, 1855. It was made by Messrs. WILLIAM BROWN & Co., of Glasgow, who were, to the best of our belief, the first makers of it in this country, and by whom we were regularly supplied; but from the smallness of the quantity produced (only 3 to 4 cwts. weekly), and its imperfection, especially in hardness, we abstained from offering candles made entirely from it, and merely employed it as an ingredient with other materials in the manufacture of the better class of candles. So far back as 1851 we had assisted in the attempt to obtain paraffin from the bogs of Ireland. It was not until November, 1856, that we received supplies; and from this source, and a quantity of Rangoon paraffin, we, in March, 1857, manufactured and put into the market for the first time paraffin candles of English make. The price at which they were introduced was 2*s*. 4*d*. per lb.

The manufacture of paraffin has since largely increased. The following figures, according to Mr. KENNEDY, express the present annual production in Scotland:—

Shale used in Scotland, ...	800.000	tons.
Crude oil produced, ...	25,000.000	galls.
Paraffin, ...	5.800	tons.
Lubricating oil, ...	9,800	"
Sulphate of ammonia, ...	2,350	"

To carry out this manufacture about 500,000 tons of fuel were required.

Paraffin before being made into candles requires purification and bleaching. The following process, "HODGE'S," is carried out on a large scale at PRICE'S CANDLE CO. The crude paraffin having been first separated from rough impurities, is cast into cakes and allowed to cool slowly, so as to form into well-developed crystals. The casks are then placed on a bed of absorbent or porous material, and are while thus placed exposed to a temperature sufficiently high to render fluid the more easily melted matters with which the crystallized paraffin is mixed, but insufficient to melt the paraffin. The melted portions then flow out from between the crystals of paraffin, and into the absorbent or porous materials on which the cake rests. The process may be repeated until the separation of the solid from the liquid hydrocarbons has been effected as completely as is desired.

The partially purified paraffin is by no means colourless, and still possesses considerable smell. Its further purification may be effected as follows, though many processes have been devised. After being melted by steam, it is poured into a tank and agitated by means of air, with from 5 to 10 per cent. of strong sulphuric acid; the sulphurous acid evolved, resulting from decomposition, is conveyed away by a suitable apparatus. The agitation is carried on for some hours, the time depending on the quality of the paraffin. After allowing the whole to rest for some time the paraffin is drawn off, and digested with animal charcoal for some hours; the latter is allowed to subside, and the liquid, if not quite bright, is passed through a filter kept warm by a steam-jacket.

Lately, other bleaching agents have been used. FORDRED, LAMBE, & STERRY, use fuller's earth as a decoloriser of paraffin, in lieu of animal charcoal, whatever the previous process of purification may have been. About 12 per cent. of powdered fuller's earth is added to the melted paraffin, at a temperature of about 230° Fahr., and well agitated, and after subsidence the clear paraffin is run off. The inventors also state that in all their processes, they can replace the fuller's earth in great part or wholly by marl clay, or other readily attainable natural substance of like character. The fuller's earth or analogous substances may be re-used, and the paraffin remaining adhered may finally be recovered from it by washing with agitation or by other suitable means. This discovery of Messrs. FORDRED, LAMBE, & STERRY, has proved of great value, and has done much to bring solid paraffin into domestic use.

ARTHUR SMITH and FRED. FIELD have patented a process in extension of the above. Fuller's earth and many other natural silicates are undecomposable even by strong acids, although certain silicates of lime or magnesia in all these bodies are decomposed when the acids are concentrated, forming a gelatinous residue of silica, and solutions of the bases. It occurred to the patentees that, by forming artificial silicates and employing them instead of the natural silicates, the paraffin or other hydrocarbons might be separated by the addition of very weak acidulated water. They experimented with the silicates of calcium, magnesium, manganese, iron, and some others, and although all answered admirably, they came to the conclusion that the magnesium salt was the best, a less amount being required to insure the full bleaching action required. At the first glance, any of these substances, even the lime salt, seems too costly to admit of practical application, but this is not the case.

The magnesium silicate is formed by precipitation of magnesium sulphate by sodium silicate. The precipitate is washed thoroughly by decantation and dried by steam. F. FIELD states that the success of this process depends upon the purity of the salt, and the manner in which it is dried. If the gelatinous mass of magnesium silicate were simply desiccated without previous washing, and the soluble saline body (in this case sulphate of sodium) retained, the porous structure, or whatever it may be, of the silicate, would be, so to speak, stopped up, and all bleaching action impeded. And if the washed product were heated to redness, its decolorizing power would also be destroyed. It must be dried at 212° Fahr. and no higher. Fuller's earth, which is simply ground, contains naturally a large quantity of water, but if heated to redness it is of no avail in paraffin refining. And yet a more singular fact is this, that although we must have a hydrated compound, no bleaching action takes place until the water is separated. Melted paraffin may be agitated either with fuller's earth or artificial silicate for any length of time, without any perceptible action, at a temperature slightly higher than its melting point. The colour disappears when the water is driven off, as if it took its place.

The value of paraffin for candle making depends much on its melting point. FRED. FIELD does not think the difference in the melting point of the different samples of paraffin is as yet understood. He has had samples of paraffin, the melting points of which varied from 130° to 135° Fahr., being as hard as it was possible to make it, and others with melting points as low as 90°, which were yet exactly of the same chemical composition. It is, however, certain that a paraffin of low melting point has always a lower specific gravity than one with a high melting point. Thus there would be about 10 per cent. difference in specific gravity between two samples whose melting points were respectively 90° and 140° Fahr. It is also very remarkable, that if stearic acid which melted at 130° Fahr. were mixed with paraffin which melted at 130° Fahr., the product would be a fusible mass melting at 114°; and if a paraffin with a lower melting point, say 90° Fahr., were mixed with stearic acid, a liquid would be produced remaining liquid at the ordinary temperature of a room. This seems analogous to the fusible alloy made of lead and bismuth, which melts at a point much below that of either of the metals employed.

Candles are made from paraffin mixed with 5 to 15 per cent. of stearin. To prevent crystallization the moulds must be heated to 190° Fahr. (87°·7 C.) before filling, and must be cooled very gradually. Paraffin candle-making machines are fitted with hot and cold water apparatus to insure regularity in working.

Paraffin will not dissolve aniline colours. The tinting material of coloured candles is therefore dissolved in the stearic acid which is used to dilute the paraffin. The colour then remains mechanically suspended. If a tinted candle is melted, and the liquid paraffin passed through bibulous paper, the filtrate is white and the dye remains on the filter.

The insolubility of certain colouring matters, especially those from aniline, may be employed successfully in determining the freedom of paraffin from stearic or other fatty acids. Pure paraffin may be subjected to a temperature of 212° Fahr. with rosaniline for some time, and yet will not take up any of the colouring matter. If, however, it contains only 2 per cent. of stearic acid a pink colour is developed; and if there is as much as 5 per cent. the whole mass becomes crimson.

WAX.—Various organic compounds, of animal and vegetable origin, but differing in composition and physical properties, are designated by the term wax.

Bees' wax (*Cera*) is the principal wax used for candle making.

For a considerable period it was an undecided point among chemists and physiologists, whether the insects which afford wax collected it in its ordinary state from flowers as a part of their food, or whether they produced it by the action of their digestive or other organs. The experiments of HUNTER and HUBER, however, prove that the insect does produce wax; and that it is the work of a certain organ which forms a part of the small cysts or sacs, situated on the sides of the median line of the abdomen of the bee, which may be observed by raising the lower segments of this part of the insect's body, having small spangles of wax arranged in pairs upon each of them. All bees, except the males and queen, in which they are never observed, are provided with eight of these sacs or tunics. Moreover, bees which are fed on sugar elaborate large quantities of wax.

In China wax is produced by a species of *Coccus*. The insect punctures the branches of certain trees and the wax exudes, enveloping them in a soft white coating, which is removed by dipping in hot water. This wax is called "Pela," "vegetable insect wax," and "vegetable spermaceti." According to BRODIE it consists of cerotate of ceryl. In its physical appearance it closely resembles spermaceti. It is snow-white, crystalline, brittle, and fuses at 179°·6 Fahr. (82° C.). By dry distillation it yields cerotic acid and cerotin.

Japanese wax is termed "tree wax," and also, though improperly, American wax. It is not a true wax, being decomposed by treatment with potassium hydrate into palmitic acid and glycerin. It is yellowish white in colour, and about the consistence of bleached bees' wax. It is obtained from the root of the *Rhus succedanea*.

Japanese wax is met with in commerce in round cakes. It fuses at 107°·6 Fahr. (42° C.).

Carnauba wax is described as the outer coating of the leaves of a kind of palm tree, *Kopernicia cerifera*. It is imported from Rio Janeiro, and on account of its high fusion point, 182°·3 Fahr. (83°·5 C.), is used in candle making to improve fats of low fusion point.

Palm wax is obtained from the bark of the *Ceroxylon andicola*, a tree met with on the Cordilleras. The outer bark is scraped from the tree and boiled in water, and the molten wax collected from the surface of the water when cool. It fuses at 181°·4 to 186°·8 Fahr. (81° to 86° C.), and much resembles Carnauba wax.

The berries of the *Myrica cerifera* contain much wax. The fruit of the plant is boiled with water, when the wax separates and rises to the surface. Myrica wax is imported from the southern states, U. S.

A variety known as Ocuba wax is imported from Para, Brazil; it fuses at 96°·8 to 140° Fahr. (36° to 48° C.).

Wax is produced in moderately large quantities in England. The quality of English wax is considered to be far superior to that of other countries; the quantity is, however, too small for all requirements, and therefore a great deal is imported from Gambia, Mogadore, Ceylon, Singapore, North America, and Brazil. The Gambia wax is difficult to bleach, and is apt to turn brown in a short time. The wax which is sometimes imported from Brazil, and is produced by a kind of black bee which hives under ground, is soft and exceedingly tenacious, and the usual bleaching process seems to have no effect upon it. It is of a dark mahogany colour. By far the largest quantity of wax imported comes from Corsica.

As obtained from the honeycomb of the bee, and from its other sources in the natural state, wax has various shades of colour; that procured by pressing out the liquid contents of the honeycomb, and washing and melting the residue, is yellowish.

Wax is purified from the extraneous matters which generally accompany it, by melting it in hot water or by steam, either in a copper, tin, or wooden vessel, and drawing off the supernatant oily-looking fluid into an oblong vessel, the bottom of which is perforated, for the purpose of distributing the liquid material over horizontal wooden cylinders, which are kept revolving half immersed in cold water. The fluid wax is by these arrangements readily solidified in thin sheets or ribbons, which are afterwards exposed to the bleaching action of air, light, and moisture. On the large scale this bleaching is effected in a way analogous to the old method of bleaching linen. A field with a southern aspect is selected, on which a number of uprights are fixed, and these are used to support strips of canvas or other cloth, fastened horizontally to each of them; upon this cloth the thin shreds of wax are laid, and occasionally watered till the yellow colour disappears. The field should be as sheltered as possible, in order that the light leaves of wax may not be blown off the cloths. The leaves are turned frequently and watered at regular intervals; when the colour seems stationary, and no further improvement appears to be effected, the wax is collected, fused with water, and treated in every respect as before, and again brought to the bleaching ground, where the process is continued till the wax becomes sufficiently white. For greater security against the wind, it is usual to draw a net over the wax spread on the cloths after they are properly watered. In France, where the bleaching of wax forms a considerable industry, bitartrate of potassium is used for the purpose of effecting the purification more quickly. The salt is mixed with the hot water in the first fusion of the wax. The process of bleaching already alluded to then becomes either wholly unnecessary, or is, at least, much shortened.

Neither chlorine gas nor bleaching powder can be used in decolorizing wax; since they render it brittle, and, when used for candles, cause it to smoke and to throw off hydrochloric acid in the act of burning.

In 1859 Arthur Smith patented a process for bleaching wax by the use of bichromate of potassium and dilute sulphuric acid. The bleaching is effected in a few hours, but the cohesion of the wax is somewhat impaired.

Ingenhol gives the following recipe:—

The wax is to be melted, and 2 ozs. of pulverized nitrate of sodium added to every pound weight, and then 1 oz. of strong sulphuric acid, previously diluted with 8 ozs. of water, is gradually poured in, the whole being warm, and stirred while the liquid is being added. The vessel in which the ingredients are brought together should be rather large, as the mixture swells up considerably.

After allowing the wax to cool a little, the vessel is filled with boiling water and set aside for the wax to solidify; when cold it is removed to another vessel and treated with a further charge of hot water, and again cooled; this operation is repeated till all the sulphate of sodium and any trace of nitric acid are removed. If nitric acid remains in the wax it is apt to communicate a brownish colour, which is objectionable.

Pure bees' wax is white, transparent, tasteless, inodorous, and insoluble in water; it fuses at about 145° Fahr. (62°·7 C.), and softens, so as to be kneaded and moulded, at 85° to 90° Fahr. (27°·7 to 32°·2 C.); it has a specific gravity of ·960 to ·966 when solid, but in the melted state, at a temperature of 178° Fahr. (81°·1 C.), the density is 0·834, and at 200° Fahr. (93°·3 C.) it is only ·8247. At 32° Fahr. (0° C.) wax is hard and brittle.

When treated with boiling alcohol repeatedly, a considerable portion of it is taken up, leaving from 10 to 20 per cent. of an insoluble waxy substance called myricin, which is much heavier than ordinary wax, being about the same density as water. The alcoholic solution on cooling deposits the extracted matter; it is called ceroten, and when well purified by repeated crystallizations from alcohol, melts at about 162° Fahr. (72°·2 C.). It appears from Brodie's investigations that this body is chiefly composed of cerotic acid ($C_{27}H_{54}O_2$). When wax is submitted to distillation scarcely a trace of the cerotic acid remains, although when distilled alone it volatilizes unchanged.

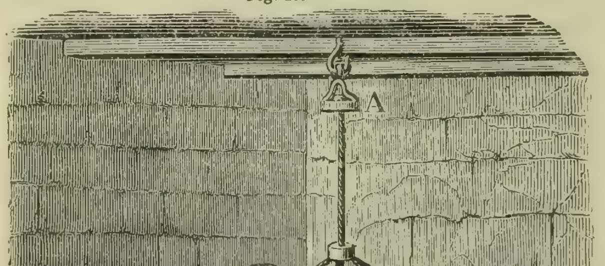
The insoluble substance remaining after the extraction of the ceroten is known as myricin, and consists of palmitate of myricile ($C_{46}H_{92}O_2$) = $C_{16}H_{31}(C_{30}H_{61})O_2$. In addition to these wax contains 4 to 5 per cent. of a body named cerolein, and to which the solidity of wax is attributed.

Wax is not well adapted for making candles by moulding, on account of the tenacity with which it adheres to the mould, and its great contraction on cooling; these difficulties are, however, in a great measure overcome by using glass moulds provided with a casing of gutta-percha. When the candles are to be drawn, the moulds are rapidly dipped into hot water and taken out immediately, by which procedure the glass dilates sufficiently to allow the candles to be removed with facility. The practised hand draws the candles as the moulds are emerging from the hot water. It is well to state that the manager of one of the largest wax candle factories in London has never seen moulded wax candles.

The wicks for wax should be much less than those for any candles yet described. Twisted unbleached Turkey cotton is invariably used, as apparently the fibre resists the temperature of the highly heated wax during combustion better than the usual variety. Plaited wicks are not so well liked as plain, since the plaiting somewhat diminishes the capillary attraction. Their size should be so proportioned that, when the candle is burning, the whole of the melted matter will be absorbed, leaving the cup below almost empty, a full light at the same time being produced.

The basting method is that which is most generally practised; and after sufficient wax has adhered to the wick, the finishing is executed by rolling in the manner about to be described.

Fig. 27.



The ends of the wicks are protected from the wax by a small tin tube or tag, placed thereon for the purpose. Before using the wicks they are heated in a stove, so as to be well dried; they are then taken, and each wick threaded into the metal tag here alluded to, by means of a brass wire catch; an operation, however simple in itself, which should be performed with care, so that the end of the wick may not get charged with the melted material.

This being accomplished, the wicks are conveyed to another workman, whose business it is to pour the melted wax upon them. He performs this operation by suspending the wicks to a hoop placed over a caldron of melted wax, and pouring the liquid on each in succession with a ladle, taking the precaution to cause the wick to revolve on its axis by the motion of the fingers (Fig. 27). When the candles are about one-third made they are allowed to cool for a short time, and then a second basting applied till they are half made, a point easily discerned by the eye, or by the aid of a balance. While still warm, they are rolled between marble slabs to render them of a uniform thickness. The end of the candle is shaped at this stage of the process as follows:—The workman places five or six candles beneath his roller, the slabs being slightly moistened to prevent the wax adhering to them, and by means of a knife cuts off about three quarters of an inch, so as to remove the metal tag on the end of the wick. After this operation is performed, the finished ends of the candles are attached to the ring and suspended as before over the caldron, and the material ladled upon them till they are sufficiently large, when they are rolled as before; and finally, the conical end cut off by a knife to make them of equal length.

When the candle is long, it is usual to bore a hole at the base in its centre to fit upon the spike of the stand upon which it may be placed; and lest this might cause the wax to crack, the end is bound round with a riband stiffened or imbued with melted wax. The ponderous lights burned in churches abroad are made by spreading the wax upon a slab, and placing the wicks horizontally upon it, then folding over the sheet of wax, and finishing the candles by rolling in the usual way. The large candles used in English churches, Westminster Abbey for example, are made by the "basting process," the workmen ascending a ladder to gain command over the wick.

Wax tapers are made by winding the wick upon a drum, and leading it under a guide roller placed in a trough of melted wax; from this it passes through a series of holes on to a second drum, the operation resembling somewhat that of wire-drawing. For white tapers a little tallow is added to render the wax pliable; for coloured, resin and turpentine. The coal-tar colours are now largely used for tinting wax candles and tapers, as well as the following colours:—

Blue—Artificial ultramarine.
Green—A mixture of verdigris and emerald green, or verdigris only.
Yellow—Chromate of potassium—chrome yellow.
Red—Vermilion.
Pink—Madder lake.

Spermaceti Candles.—The candles made from spermaceti are highly prized on account of their beauty and illuminating qualities, and notwithstanding their costliness, are largely exported to India.

The first step is to separate the solid or "head matter," as it is called, from the sperm oil as it comes from the ships, which is done by filtering it through a long cylinder of bagging lined with linen. The bag is so constructed that, at one end, it is attached to a feed pipe opening into the reservoir, elevated 4 or 6 feet above it, while the other end is bound by a cord. On opening the feed pipe, the cylinder is readily filled, and the pressure then communicated by the stock of matter in the tank forces the oil through in considerable quantities, while the solid spermaceti is retained. Autumn and winter are the seasons for the filtration of the sperm oil, technically "bagging."

The bags are open at both ends, so that the crude or "bagged sperm" is easily removed; it has a dingy brown colour, in consequence of the oleaginous matter which it retains. Considerable portions of this oil are abstracted by the first pressing, which in large factories is applied by the hydraulic, though in lesser works the screw press is used with effect; in either case the sperm is inclosed in suitable quantities in hempen bags, and placed in the frame with plates interposed between them. After receiving the pressure of about 80 to 90 tons, and when no more oil is afforded, it is taken out and melted in the same manner as stearic acid, then drawn off into tinned cases and granulated; finally the blocks, after being thoroughly crystallized, are grated to coarse powder by means of a revolving cylinder studded with knives; this powder, which is collected in a suitable bin beneath the cutter, is filled into cloths with twine wrappers and subjected to the action of a hydraulic press, capable of exerting a force of 600 tons. Some solid matter is forced out with the oil at this stage, and on this account the latter must be passed a second time through the filtering bags.

This completes the process of cold pressing. A large quantity of oil is, however, still retained and cannot be separated by mere pressure. Recourse is therefore had to saponification. To this end the blocks of spermaceti are melted in a large iron vessel, and then boiled for some time with a solution of caustic soda, specific gravity 1·109, in the proportion of 1½ gals. of the lye to 40 of the liquid fat. The oil combines with the alkali, and rises to the surface in the form of soap. Should there be an excess of alkali over what is necessary to combine with the oil on the boiling of the liquid, it would act upon the solid matter and convert it into a soap which would be carried off with the other impurities. To prevent this the solution of the alkali should be weak, or the melted matter ought to be maintained at a low and equalized heat till the oil is taken up, the combination being assisted by stirring the mass. The melted material is now allowed to repose at this gentle heat, during which the soap that has been formed rises to the surface and is carefully skimmed off. To remove all the saponaceous compound in this operation, the whole of the material is raised to about 250° Fahr. (121°·1 C.), and washed with small successive portions of water; meantime the scum as it rises to the surface is carefully removed, until the whole of the melted matter is clear. It is now drawn off into flat tin moulds and left to crystallize; after this is done, the cakes are again ground to powder and submitted to hot pressing in a horizontal steam press in bags of linen, interleaved with horse hair mats and hollow iron plates, in the same way as stearic acid.

Finally, the cakes are once more heated and boiled with a strong alkaline lye, at a temperature approaching 235° Fahr. (112°·7 C.), taking care to remove any extraneous matter that may rise to the surface during the operation. When no more impurities are thrown up, the spermaceti is washed by adding water at intervals in small quantities, the heat being moderated a little at the same time; and as the water falls to the bottom it effects a further purification, leaving the supernatant fluid colourless. It is now cast into blocks and crystallized, and stored as candle stock. Spermaceti is usually mixed with 3 per cent. of wax or paraffin, to destroy its highly crystalline structure; it is "moulded" in the usual way, with plaited wicks that require no snuffing. Occasionally the spermaceti candles are cast without any admixture of wax, the moulds being raised to a higher temperature just as with stearic acid. Some manufacturers, in order to make the spermaceti appear like wax, use gamboge to give the desired yellow tint; such candles are known as transparent wax.

CAOUTCHOUC.—See India Rubber.

CARMINE—See Cochineal.

CEMENT. — *Ciment*, French; *Cäment*, German; *Cæmentum*, Latin.—In speaking of cements, attention will be given to the more substantial materials used under that name in architecture, as well as to those employed by the jeweller, the marble mason, the manufacturer of china, &c. The term cement is usually applied to such bodies as are capable, by their interposition, of uniting homogeneous and heterogeneous substances, without the aid of mechanical rivets. To do this, however, in such a manner as is sometimes observed in bodies that have been cemented, it is evident that a more intimate union must be effected than that of simple adhesion; in fact, that a chemical combination between the components of the cement and those of the bodies to be united must take place; whereas, in other cases, the virtue of the cement lies in its great adhesiveness, by which it excludes air from the broken surfaces. Many of the preparations, into the composition of which resins, gums, and albuminous bodies enter, act by adhesion, while the mineral cements used in architecture behave differently, in consequence of a chemical combination being formed between them and the body of the substance.

Resinous Cements.—Under this head might be included those varnishes and glues which are employed by the joiner or cabinet-maker, but as these may be more fully referred to subsequently, they will not be further noticed in the present article. Some of these varnishes, when mixed with other substances, form excellent cements: thus, rosin and beeswax melted together, and thickened with brick dust, form a cement used for joining glass and metal work; so also asphalt mixed with chalk may be used for cementing stones together.

MISCELLANEOUS CEMENTS.—A compound for connecting broken pieces of glass or china-ware is known as *diamond cement.* It is prepared by steeping isinglass in water till it swells, and then dissolving it in proof spirit, to which a little gum-resin, gum ammoniacum, or resin mastic, dissolved in the smallest possible quantity of alcohol, is added. Previous to being applied to the fracture it should be gently heated. It resists moisture to a certain extent. HÄULE recommends that 2 parts of shell-lac be dissolved in 1 part of oil of turpentine, and cast into sticks. The same may be employed instead of glue, by dissolving it in spirit, and evaporating to the consistence of a syrup.

KELLER gives the following formula for the preparation of a cement for the same purposes:—2 parts of finely-chopped fish glue are steeped for twenty-four hours in 16 parts of water, then boiled till the liquor is reduced one half; 8 parts of alcohol are added, and the whole strained through linen. While still warm, it is mixed with a solution of 1 part of mastic in 9 of alcohol, and half a part of gum ammoniacum in fine powder; the latter is added gradually, and intimately mixed by maceration. When this cement is used, the parts to which it is applied should be heated, allowed to cool, and then covered with the hot fluid and pressed together. In five or six hours it becomes perfectly hard. This cement is not adapted for very porous substances; for these a concentrated solution of shell-lac in spirit of wine answers best. It should be applied to the thoroughly dried surfaces of the parts to be connected.

A very good cement is formed when shell-lac is dissolved in a concentrated solution of borax. Albumen of egg mixed with quicklime makes a very strong cement, but it does not resist water effectually: it is employed to unite pieces of spar, and marble ornaments to which moisture has little access. Coppersmiths use a similar compound for securing the edges and rivets of boilers, but substitute blood for the white of egg. A very similar cement is prepared by boiling the casein or cheese of skimmed milk in a large quantity of water, and then incorporating the solution with quicklime upon a slab or in a mortar. This strongly unites fractured pieces of stoneware.

VARLEY'S Cement is made of whiting, resin, and bees'-wax, the proportions being 16 parts of the first, well dried by heating it to redness, melted with 16 of black resin and 1 of the wax, the whole being stirred well during the fusion.

An excellent cement, known as *Singer's*, for connecting articles of brass and glass, and adapted for constructing philosophical apparatus, consists of 5 lbs. of resin, 1 of bees'-wax, 1 of red ochre, and 2 table spoonfuls of plaster of Paris, all melted together. URE'S formula for a cheaper compound, adapted for joining voltaic plates into wooden troughs, is 6 lbs. of resin, 1 of red ochre, half a pound of plaster of Paris, and a quarter of linseed oil. The ochre and plaster should be calcined beforehand, and added to the other ingredients while in fusion. A cement nearly colourless is obtained from white wax, resin, and a little Canada balsam. Jewellers sometimes use resin mastic by itself to attach, by heat, cameos of white enamel or coloured glass to a real stone, as a ground to produce the appearance of an onyx. Mastic is likewise used to connect false backs or doublets to stones, to alter their hue. These cements require to be softened by heat before they are applied.

A cement, said to be used by Turkish jewellers, is prepared as follows:—Isinglass is dissolved in brandy or rum, so as to form a strong glue; two small pieces of gum albanum, or gum ammoniacum, are added to every 2 ozs. of this liquid, and triturated until dissolved; and a solution of two or three pieces of mastic, the size of peas, in the smallest possible quantity of alcohol, is added. The cement is kept in a closely stoppered phial: when required for use it is liquefied by placing the phial in hot water.

A concrete, which becomes as hard as stone when set, is made from 20 parts of river sand, 2 parts of litharge, and 1 of quicklime, well ground with linseed oil into a paste. It is very applicable for repairing broken stones, such as steps of stairs and the like. A similar composition, in which porcelain clay replaces the sand, is made for coating brick walls, terraces, &c., and bears the name of mastic. Ordinary asphalt is a cement made from bitumen, chalk, silicious matter, and oil, but this has been already treated in a separate article.

Shell-lac and caoutchouc afford a glue of such adhesiveness that masts may be made by splicing the wood together, and joining them with this varnish, no other fastenings being required to give security; and what is remarkable is the fact that, when such masts have been broken, the fracture has never been observed to take place where the splice has been, but where the wood was whole.

This cement, technically known as "Marine Glue," is formed by dissolving, in about four gallons of coal-tar naphtha well rectified, about one pound of caoutchouc, divided into small fragments. The mixture is well stirred from time to time, till the solution becomes perfect. After ten or twelve days, when the liquid has acquired the consistence of cream, two parts by weight of shell-lac are added to one of this liquid. The mixture is put into an iron vessel, having a discharge-pipe at the bottom, and heat applied. During this operation the whole is kept stirred, and the liquid flowing out of the discharge-pipe in a warm state is spread out upon slabs, and preserved in the form of plates.

When use is to be made of this glue, it is heated in an iron vessel to the temperature of 248° Fahr.. and applied hot with a brush to the surfaces to be joined, taking care to spread it in a uniform layer. The pieces of wood are then brought together, and firmly pressed. If the glue should get hardened before the connection be made, it should again be softened by bringing it to a temperature of 150° Fahr. by passing heated rollers over it, and then the joining quickly made. When the surfaces of contact are well dressed, a thin coating of glue on each is sufficient; but if there be any irregularities in the wood, the glue should be made sufficiently thick to fill these up. Not only may the glue be used for joining shreds of beams or posts, but also for repairing split pieces. The cracks, or crevices, are filled with the glue while at a heat of 248° Fahr.

A very good composition for connecting iron pipes is made from iron filings and chloride of ammonium, ground together, and moistened with as much water as will give the mixture a pasty consistence. It was formerly customary to incorporate sulphur as an ingredient, but it did not increase cohesion; this effect being produced by the oxidation of the iron, which causes it to expand and solidify. The best proportions are 99 of filings and 1 of the sal-ammoniac. Another preparation of a similar nature is formed by mixing 4 parts of iron filings, 2 of potter's clay, and 1 of pounded potsherds, the whole made into a paste with a concentrated solution of common salt; on drying, it becomes very hard.

BUILDING CEMENTS.—Having thus briefly enumerated the principal cementing materials employed for miscellaneous purposes, attention will now be directed to that more important part of the subject which relates to architecture. In this department, the substances which are commonly known by the term cement, whether hydraulic or otherwise, deserve particular notice, as they contribute to the solidity and durability of the building in a remarkable manner. And being so important, it would be well if architects of the present age devoted more of their studies to the consideration of this subject.

How well do the enduring architectural remains of Egypt, Greece, and Rome, as also many of the edifices of the early and middle ages of our era, testify to the quality of the binding medium employed, having withstood the assaults of time, whilst numerous others of later date have mouldered away, in consequence of this material being imperfect!

It has been already stated that the action of hardening, as manifested by some bodies, is due to a chemical as well as a mechanical agency; such is especially the case with mortars, and hence it will be necessary to dwell somewhat in detail upon this subject, commencing with ordinary or common mortar. But, as introductory to this, it may be proper in the first place to say a few words upon the principal component in cement—the lime, and to give a short description of the manner in which it is prepared.

LIME.—*Calcium monoxide* (CaO).—The great source of this compound is the various chalk and limestone (calcium carbonate, $CaCO_3$) deposits found in the geological formations of every country; but besides these, very large beds of calcium salts exist in many other states, and indeed it is met with more or less in all soils, in the ashes of most plants, and also in the bones of animals combined with various acids.

Limestones and other calcareous rocks never exist in a pure state; for, besides the carbonate of lime, which is the principal and nearly the entire ingredient, other substances, such as magnesia, clay, ferruginous and bituminous matters, are contained in them, and from these they obtain their specific names. Only calcareous spar, and a few other minerals, are entirely composed of pure carbonate of lime. Besides the designations *magnesian*, *argillaceous*, &c., limestones are often named from the peculiarity of their *molecular* arrangement. Thus mineralogists give the appellation of *compact*, *pulverulent*, *chalky*, *lamellar*, *saccharoid*, *granular*, *concreted*, *oolitic*, &c., to different limestones, according to their respective species.

Ordinary lime may be prepared from most of these; but the facility of so preparing it is greater in some cases than in others, and the lime itself manifests different characteristics. All that is required is to expel the carbonic acid; and heat is the best agent for effecting this. Kilns of various construction are employed, wherein limestones are burned by the agency of peat, wood, or coal, according as the facilities of the locality offer the one or the other in more or less abundance. The proper form of the kiln is a matter of much interest to lime-burners, as a great economy in fuel may be effected by having it of a certain shape; besides that, when properly constructed it burns much better.

The more common form of kilns exhibits an elliptical section, the upper end being wider than the lower one, wherein is the eye or draft hole. This shape is more advantageous than that of an inverted cone, in which some kilns are occasionally constructed, for the former concentrates the heat more towards the top, and therefore the limestone in this part is acted upon more than it would be if the top or mouth were wider than any other part. Greater facilities are also afforded for drawing off the burned lime, and the kiln itself is less injured, when the form is elliptical or oval.

But where large supplies of lime are required, these comparatively rude forms are laid aside altogether, and a more scientific construction is adopted.

The lime kilns are divided into two classes (1), intermittent kilns, or those whose working is interrupted at each withdrawal of burned lime; and (2), continuous kilns, the operation of which proceeds uninterruptedly.

Fig. 1 shows a vertical section of one of the best of the intermittent kilns, and Fig. 2 a transverse vertical cut, showing the position of the shed placed over it. In the first of these, *a* is the side opening to the back of the fuel chamber, which is about 2 feet square, with iron bars across. On each side of this chamber is an aperture, by which the air is carried to the back, and the entrance of these to the fire is shown at *a* above. The top of the kiln is arched over, the arch springing from *b*. The kiln is fed through the apertures in the arch, and which have cast-iron covers, *c c c*, with lids turning on a pivot appended to them, by means of which the draught is regulated. In Fig. 2 the fuel chamber is shown at *d*, and *e e* are the air-flues between the double doors of the chamber; A is the space where the loading carts stand; *c*, the cast-iron cover of the feeding aperture, and *h*, the cover of the chimney of the kiln shed, B B. This shed over the mouth of the kiln is very beneficial in keeping the materials dry, and heating them more or less before they are admitted into the shaft. C represents the door by which the limestone is conveyed into B B. The kiln is usually built on the face of a steep bank, and is constructed of fire-brick or fire-stone; the height of the kiln is about 20 to 30 feet, the diameter in the middle is 7 feet, and it is contracted to 3 at the top and bottom.

Fig. 1.

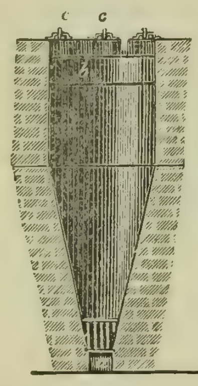
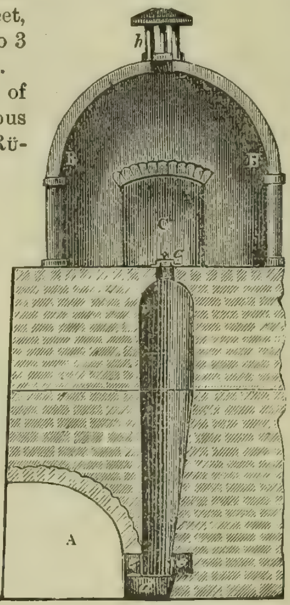


Fig. 2.



As an economiser of fuel, the continuous lime-kiln used at RÜDERSDORF is the best. Fig. 3 is a vertical section of this kiln, which is heated by wood and peat. The shaft, C, is like the foregoing, formed of two truncated cones, and is about 45 feet in height. It is 7 feet in diameter at the top and base, and 10 feet in the widest part, opposite where the fires are situated. In the construction of the shaft, limestones may be used in the walls; but that part to which the heat reaches should be faced with fire-brick, the thickness of which increases from half a brick to a brick and a half in thickness as it approaches the seat of the heat. This lining reaches to the height of 40 feet, and is shown in the figure at *d′*; the wall being represented by *d d*. All these are encased in an exterior wall, *e e*, built of the same material as *d d*, leaving a space of a few inches in diameter, which is filled with ashes and other non-conducting material. This serves to retain the heat, and likewise to afford room for the expansion of the firebricks and stones which takes place when strongly heated. An outer wall, B B, incloses the whole, and the intermediate space is divided into several compartments by means of arches, *p p p*, which serve as drying rooms for wood, fuel, &c. The fires for heating the limestones are three, four, or five, and are seen at *b b*, placed at equal distances from each other. These are arched over, and the arches are lined with firebrick. The grates are composed of two perforated tiles, resting in the middle upon the brickwork, *f*; the perforations in these tiles, by which a current of air, entering by the passage, *h*, is admitted to the fire, are about 1 inch wide, and 3 or 4 in length. *g* is closed by an iron door, as also the outlet from *i*, where the cinders collect at first, and then fall into the channel, E, whence they are cleared off through a door, *z*. These doors are left shut until the space, *i*, is filled, and the cinders have sufficiently cooled to be removed conveniently. The draught-holes where the burnt lime is abstracted are seen at *a a*; these are closed with iron doors, which are luted, except at such times as the content is being taken out, in order that the air may not enter at these orifices to cool the kiln. To facilitate the descent of the lime to these apertures, the sole of the kiln is inclined downwards towards them. As the lime is very hot when drawn, the canal, *k k*, is constructed to afford the men protection from the heat; the canal communicates with the chamber P, into which the hot air ascends, a current being instituted in this passage by the fire.

Fig. 3.

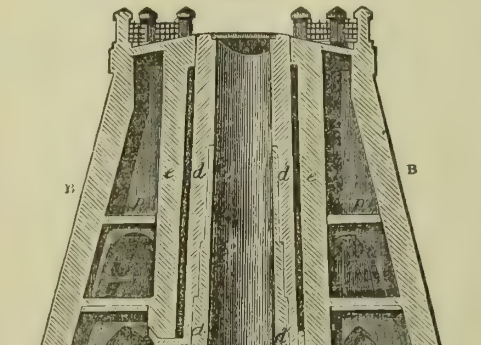


Fig. 4.

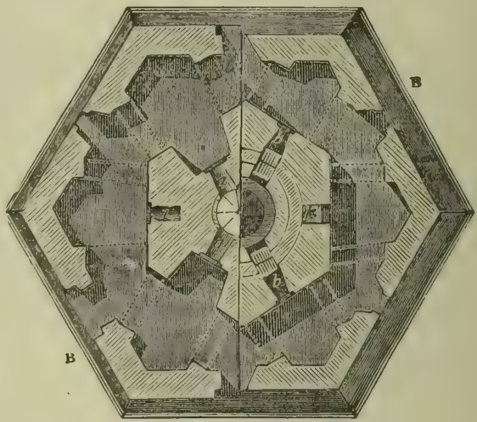


Fig. 4 shows the plan of the preceding, at the lines, Z Z, the section being horizontal with the fires, *b b*, on the one side, and with the draught-holes, *a a*, on the other. When the kiln is set in operation, the part of the shaft to the level of the fires is filled with limestone, and fires lighted in *a a a*, which are kept burning till the calcination is completed. A fresh quantity of limestones is now let down by buckets upon that already burned, and the supply continued till the shaft is quite full, when a heap, 3 or 4 feet high, is raised over the mouth. The doors at *a a a* being luted on, so as to shut off the draught, the fires are lighted in *b b b*, and kept up constantly. So soon as the upper stones are observed to be well burned, the lime under the level of the fires is drawn out; this causes the top column to fall in, upon which a fresh quantity of limestones is thrown on and piled above the mouth as before. Thus the work progresses without interruption; the lime, however, is drawn only at periods of twelve hours, when about 50 cwts. are abstracted.

The time required for burning lime is affected by many causes, such as the size of the stones, their freshness, and density. It is well known that compact limestones are more difficultly burned than such as are more porous; also, that moisture to some extent facilitates the expulsion of the carbonic acid, even at a lower degree of heat than is required when the limestone is dry. The usual practice of moistening the stones is not so economical as introducing a jet of steam into the kiln; for, in the first case, the heat serves only to evaporate the water before the material can be brought to redness, by which much fuel is wasted; but in the latter, the limestone may be heated to redness, and the steam admitted, when it will be most serviceable. Where kilns like the one above described are being constantly worked, there is a great saving of fuel effected by them; but it is evident that they are adapted only for such places as require a very large quantity of lime, and where, consequently, they can be kept in operation without intermission. Theoretically, the consumption of fuel in causticising or burning lime is only one-tenth of the weight of the limestone; but in ordinary practice, five or six times the quantity which theory shows to be sufficient is used; and where lime is burned for agricultural purposes, and attendance is not very regular, even a much larger amount is consumed.

It is evident, therefore, that those who are engaged in these operations would do well to give the subject their best attention. Much care is required of the lime-burner, especially if the material is of an hydraulic nature; for if he allows the temperature to rise higher than is required to expel the carbonic acid, the lime in consequence loses its property of setting or hardening. This loss of hardening power is probably due to the formation of a layer of silicate of aluminium on the surface of the lime, which prevents water from acting on the lime so as to form a paste.

MORTAR is a mixture of slaked lime and sand in proper proportions. When this mixture is spread in thin layers between stones or bricks, as in building, it gradually hardens and acquires a great degree of tenacity, in a great measure from its gradually reconversion into carbonate of lime, combining at the same time with the substance of the brick or stone, so that the whole becomes one perfect solid. The time required to effect this change is long; for although the mortar becomes sufficiently hard, in a few days or weeks, to enable the wall to bear considerable pressure, still it does not acquire the maximum degree of hardness till after the lapse of many years, and even centuries. From PLINY we learn that the Romans were in the habit of preparing their mortars some time before they were used. One of the causes of the durability of old buildings may be the long period during which the mortar has been exposed to the hardening influence exercised upon it by age; but even this, as is well known, will be ineffectual in bringing the mortar to its greatest power of endurance, unless it be made with the proper admixture of lime and silicious or other matters.

Hydrated lime, alone, is capable of forming a hard cement, but in doing so the mass shrinks very much; it cannot therefore be employed alone as a cement for binding together building materials, inasmuch as the shrinking would cause great unevenness in the construction of walls, &c. As, however, it is found that lime reacts with such bodies as are different from it in composition, especially if they be of a silicious nature, the fact has been taken advantage of, and sand employed from time immemorial to multiply the surface of contact, bring the whole of the hydrate of lime into active combination, as well with this as with the surfaces of the stones or bricks, and prevent the lime from unduly shrinking as it hardens; and thus the union is more thoroughly accomplished. Another requirement for insuring the solidification of the mortar is the presence of just sufficient moisture. If water be not properly supplied, no matter how true the admixture of the other ingredients may be, the mortar will not become firm; if kept in large quantities of this liquid, it will not solidify; and if it be dried as in a stove, it will not form a cement, but remain friable. Exposure to air (*i.e.*, to air containing carbonic acid) is likewise necessary to develop all the properties of the mortar.

Bearing these facts in mind, it is easy for the builder to prepare his mortar or cement so that it may possess all the requisite qualities. The best material is quartz sand, not very fine. When the sand is very minutely divided, then the matter becomes too dense to admit the air which is necessary for its proper solidification; on the contrary, if it be very coarse, the interstices are too large to be filled up with the lime. A good result is obtained when irregularly-shaped stones are employed, by taking a mixture of coarse and fine sand, for it has been observed that the more irregular the foreign body mixed with the lime, provided the surface of contact is sufficiently extensive, the more binding is it. Angular or sharp sand is therefore much to be preferred to smooth, round sand. When the mortar is intended to form a thin coating on the exterior, fine sand is more appropriate.

After ascertaining the materials best suited for the preparation of the mortar, the next step is to proportion them in such a way as to give the best result. This is a work of considerable importance, and any error committed in it cannot be subsequently remedied. As to the quantity of sand which should be taken, much depends upon the quality of the lime; if it be a *fat* lime, that is, if it be devoid of much foreign matters, and fall into a very fine powder in the slaking, it will require about six times the weight of sand; or 3 or 4 cubic feet of sand must be added to 1 of the semifluid milk of lime. Should the lime contain much insoluble matter, or be what is usually known as *poor*, then the volume of sand must be lessened to 2 or 2½ cubic feet. As a general rule, the sand should be mixed with as much of the cream as it will take up without increasing its bulk; and the lime should be so finely divided as to form the thinnest possible stratum between the grains of sand, which it should envelop and bind together. Before applying the mortar the bricks or stones are wetted, in order that they shall not too quickly absorb the water of the mortar.

The cause of the setting of mortar can scarcely be said to be yet determined: it was thought that the hardening was due to mechanical agency exclusively; now, however, it has been found that this is not the case, and that chemical combination contributes materially to render it firm and durable. This chemical action is not wholly confined to the formation of carbonate of lime. The action which takes place during the hardening of mortar appears to be somewhat as follows:—The carbonic acid of the atmosphere acting upon the exposed parts of the mortar forms a coating of calcium carbonate: the amount of this substance formed increases with the age of the mortar; but at no time, so far as we can learn, is the whole of the lime of the mortar converted into carbonate. Mortar from the Great Pyramid was found to contain a considerable proportion of hydrate of lime. That part of the lime is converted into carbonate during the hardening of mortar, may easily be demonstrated by adding a little hydrochloric acid to a small quantity of old mortar, when a brisk effervescence ensues due to the escape of carbonic acid gas. Besides this calcium carbonate there is also formed a small quantity of calcium silicate, by the action of the lime upon the silica of the sand and of the stone or brick; this silicate spreads over the surface of each little grain of sand, and binds the whole mass compactly together.

The formation of the carbonate continues so long as the mortar retains moisture to dissolve the lime and the air has access. Whatever may be the advantages gained from these combinations, they are not sufficient to impart firmness to the material; it is only from the combined influence of the adhesiveness of the mortar to the stone, rendered more intimate by chemical combination, that the full effects are obtained.

Much injury arises to buildings in consequence of impurities being in the materials of the mortar, more especially if they consist of humus, nitrogenous matters, or alkaline chlorides. When these are present, they produce, by their decomposition, deliquescent salts, which attract moisture and occasion damp walls, besides disintegrating the mortar, and consequently destroying its cohesive power. Particular observation should therefore be made, as to whether the sands and water employed in making mortar are free from the substances mentioned. When alkaline chlorides are contained in them they undergo decomposition, giving rise to an alkaline carbonate and chloride of calcium, which is a most deliquescent salt. So ready is this interchange, that it was once proposed as a means for preparing carbonate of soda on a large scale. The humus and nitrogenous matters, when decomposed in the presence of hydrate of lime, produce nitric acid, which, combining with the latter, yields nitrate of calcium—also a deliquescent salt—which is observed in the form of an efflorescence. The amount of sand sometimes added to mortar is so great as to entirely destroy the binding power of the material; very serious accidents have resulted from this cause.

Incrustations, however, appear on the walls, which are not occasioned by any of the forementioned causes, and consequently do not affect the quality of the mortar like those enumerated. They are composed, according to the researches of Kuhlmann, Vogel, and others, who examined efflorescences of this kind, of sulphate, carbonate, and chloride of sodium, together with carbonate and chloride of potassium; they take their rise from the limestone employed containing these bases. Probably the ash from the fuel used in burning the lime contributes more or less to their formation.

Hydraulic Mortar is made of 1 part of brick powder with 2 parts powdered lime mixed with fresh water. This mortar must be laid in very thick between the bricks, which must be well soaked in water.

Hydraulic Cements.—The common material just described is quite unadapted for the erection of docks, dams, lighthouses, and the like, in connection with large trading ports, and coasts dangerous to shipping. For such operations another variety of mortar is used, which has the property of solidifying under water, and hence has been called *hydraulic cement*. On account of the special adaptability of some species of limestones for the formation of this mortar, they are called hydraulic. Such are those calcareous rocks which contain on an average 10 or more per cent. of silica. When these limestones are burned, they comport themselves differently to the ordinary fat lime, inasmuch as they are very slowly slaked, and if the powder thus produced be made into a dough with water, it very soon hardens into a rock-like mass, and remains unaffected by that liquid. The cause of the hardening of hydraulic cements is to be attributed more to chemical combinations than to anything else; it will therefore be necessary to notice more in detail the constitution of those stones which afford a hydraulic lime by calcination, in order to trace their distinguishing quality to its proper source. With this view the following analyses of a few hydraulic limestones are transcribed.

The fresh limestones contain in 100 parts—

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Carbonate of calcium,	89·0	82·5	80·0	79·2	76·5	83·40		86·87	82·82
" magnesium,	2·0	4·1	1·0	2·5	3·0		79·16	3·90	3·76
" iron,	—	—	—	6·0	3·0			—	—
" manganese,	—	—	—	—	1·5	0·90	—	—	—
Silica,	9·0	13·4	17·0	6·5	11·6	13·97	19·14	5·00	11·76
Alumina,			1·0	3·8	3·6			4·23	
Oxide of iron,			—	—	—	1·73	1·70		1·66
Carbon,			—	2·0	—	—	—		
Water,	—	—	1·0	—	—	—	—	—	—
Loss,	—	—	—	—	0·8	—	—	—	—
	100·0	100·0	100·0	100·0	100·0	100·00	100·00	100·00	100·00

The lime obtained by burning the above, contained in 100 parts:—

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Lime,	82·0	79·3	70·0	74·0	68·3	Undetermined.			
Magnesia,	1·5	3·5	1·0	2·0	2·0				
Clay,	16·5	16·7	29·0	17·0	24·0				
Oxide of iron,	—	—	—	7·0	5·7				
Loss,	—	0·5	—	—	—				
	100·0	100·0	100·0	100 0	100·0				

No. 1 is a limestone from the Jura mountains; it is of a light-grey colour, but varies in appearance.

No. 2. Limestone from Nismes; it is yellowish-grey, and is very highly prized as hydraulic lime.

No. 3. This is a marly substance from Senonches; it is disintegrated by water in the ordinary state. Silica remains unaffected when the stone is digested in hydrochloric acid; but it is completely dissolved in caustic potash.

No. 4 is a dense limestone of unknown origin.

No. 5. A limestone from Metz; it is dense, exhibits an earthy fracture, and is of a bluish-grey colour.

No. 6 is a limestone marl from Blankenstein.

No. 7 is from Helbigsdorf, near Freiberg; and

No. 8 and 9 are two samples of excellent hydraulic limestones from the Halkin Mountain, Holywell, Flintshire; they have a compact grain and a dull grey colour. These limestones were employed in the construction of the Birkenhead docks, besides being extensively used in the construction of docks, piers, &c., in other parts of the United Kingdom. The mortar obtained from these stones sets rapidly, and so firmly that the work becomes one solid mass.

	1.	2.	3.	4.	5.	6.
Carbonate of calcium,	67·86	66·99	49·06	76·82	62·47	39·72
" magnesium,	5·62	1·67	29·32	2·81	1·35	28·48
" iron,	3·30	6·95	16·83	3·21	5·85	7·50
Alumina,	—	0·39	—	0·89	0·93	—
Total constituents soluble in hydrochloric acid,	76·78	76·00	95·21	83·73	70·60	75·70
Silica,	15·57	16·89	3·35	11·03	20·93	Undetermined.
Alumina,	4·18	4·32	0·86	2·86	7·72	
Oxide of iron,	1·13	1·72	0·43	1·86		
Lime,	0·15	0·05	0·06	0·12	0·12	
Magnesia,	0·57	0 37	0·01	0·05	0·30	
Total constituents insoluble in hydrochloric acid,	21·60	23·35	4·71	15·92	29·07	
Loss,	1·62	0·65	0·08	0·35	0·33	
	100·00	100·00	100 00	100·00	100·00	

The hydraulic quality of lime depends chiefly upon the amount of insoluble matter, the percentage of silica, alumina, magnesia, or iron, which it contains. This residuary matter is often chiefly composed of silica in the soluble modification. In examining hydraulic limestones, it is necessary to direct attention to the composition of this insoluble residue. In the preceding table, drawn up by HERMANN MEYER, this has been more particularly attended to.

No. 1. This is the limestone from Krienberge, near Rudersdörf, Berlin; it occurs below the sand. It belongs to the upper division of the shellstone, and being in a state of great disintegration, cannot be employed as ordinary mortar.

No. 2 consists of limestone nodules from the Isle of Sheppey; it is yellowish-brown, massive, and firm. These nodules are used in England for the manufacture of *Roman cement*, and occur in the London clay, which is a member of the tertiary formation.

No. 3. A limestone belonging to the shell limestone formation, which covers the layer of lead ore at Tarnowitz. It is bluish-grey, massive, and nearly crystalline.

No. 4. Cement-stone from Hausbergen. In the manufacture of cement, this stone is mixed in equal proportions with

No. 5, which is a stone from the same locality, and of a poor nature, disintegrated, dark-bluish grey, and slaty.

No. 6. The stone from which Koch's cement is made in Cassel; it is a reddish-yellow, massive, dolomitic marl, from the lower shell limestone.

Kuhlmann has shown that, besides the silica and alumina in hydraulic limestones, other substances previously overlooked in their analyses affect the solidification in a very marked degree. These are the alkalies, which he found in larger proportion in hydraulic than in the ordinary limestone. From this he deduced that the formation of hydraulic limestone was due to the infiltration of a soluble silicate through beds of chalk, by which silica would be retained; and he grounded a means of making cements, and hardening chalk, upon the same principle. His method was to digest the chalk in a solution of an alkaline silicate for a proper period, then to wash with water and dry; the silicic acid unites with the lime, and renders it so hard that it cannot be scratched by the nail.

Hydraulic limestone, if finely ground in the natural state, does not solidify; but after being well burned, and deprived of its carbonic acid, ground or slaked, and then applied as a mortar or cement, it concretes, forming a mass even harder sometimes than the natural rock. The ignition has another effect, by which the silicates, insoluble before the action of the heat, are so modified as to be decomposed by acids, which separate the silicic acid in the form of a jelly. The portion of hydraulic limestone dissolved by acids previous to burning, is that which affords a fat lime when burned and slaked; and the residue is a kind of clay composed of silicates of iron, aluminium, magnesium, lime, and alkalies, with a greater or less proportion of uncombined silicic acid. During the burning, the latter is taken up by the lime rendered caustic by the evolution of carbonic acid, and a silicate is produced which is easily attacked by acids. So perfect is this change, that almost the whole of the metals in well-burned hydraulic limestone may be removed from the silica. The interchange may be explained thus:—At first the heat causticises the stone by expelling the carbonic acid, and the metal acts upon the silicious matters at a high temperature, so that there is a compound silicate of the calcium and other metals produced, which is decomposed by hydrochloric acid.

Again, the caustic lime and the modified silicate react upon each other in the presence of moisture, so as to produce a solid stone-like silicate. In this reaction the water performs an important part; for when lime is mixed with aluminous silicates, these ingredients have little or no action upon each other, unless water be present as a vehicle to bring about an intimate molecular contact. This it does in the mortar during the solidification, by dissolving a portion of the lime, and transferring it to the silicious earth to produce the concrete cement. One great corroboration of this fact, is the necessity which exists of keeping the mortar moistened for some time till it is sufficiently hardened. In this case the change is not owing to the combination of water of hydration, although this may take a part in it; for, were that the case, many silicates which have nearly the same composition would harden under water after being deprived of their combined moisture by ignition; but no such behaviour has been observed. The only way in which the water contributes to harden the cement is, by uniting with the silicate which is formed through this medium, and producing therewith a hydrate. Besides this action resulting in the formation of calcium silicate—probably $Ca_3Si_3O_9$—another action between the lime and the alumina seems to take place, giving rise to an aluminate of calcium, $CaAl_2O_4$. This latter body is slowly acted on by carbonic acid, but so long as the cement contains free lime this disintegrating action is stopped, because as soon as the alumina is set free by the action of the carbonic acid it is presented with a fresh quantity of lime, with which it again enters into chemical union.

The mechanical state of the cement exercises an important influence; if it be coarsely ground, its powers of hardening under water are but slight, but if the cement be ground to fine powder, so many points of contact between the particles are presented, that the action described above takes place quickly, and the hardening of the mass is complete in a short time.

With a limited quantity of water, hydraulic lime at first forms a soft, friable mass; but when afterwards immersed in the liquid, it becomes as hard as stone. The time which various limestones require to harden is very variable, and all of them do not acquire an equal degree of compactness, so much being dependent upon the chemical constitution of the lime, and also upon the treatment which it receives. Some varieties solidify in the course of a few hours, whilst others require a period of thirty days before they acquire any very great degree of hardness or of binding power. The delay in the hardening of such limestones may be owing to the presence of foreign matter, such as gypsum, with which the limestone becomes covered, by the exertion of surface attraction, the water being thus prevented from entering the pores of the mass.

Hydraulic limestones are found in almost every country. Those in which the insoluble matters amount to about 10 or 12 per cent. afford a cement, the hardening qualities of which are not very great, neither are they readily developed; but when the insoluble matters reach to 20 or 25, or from that to 35 per cent., then the substance produced has the qualities required in a very marked degree, and manifests them in a short time, varying from a few hours to three or more days. Although a limestone may be so composed as to be capable of producing a good mortar under proper treatment, yet, when improperly calcined, many if not all the qualities of the stone may be lost. The burning of the limestone then, which is the chief operation, should be carefully studied, and the temperature regulated with regard to the known composition of the stone; for if the heat applied be too low, the decomposition of the silicious matters will be only imperfectly effected, whilst, if the heat be so great as to cause a semi-vitrification of those constituents, the qualities of the cement will be entirely lost, for those parts will either not slake, or else the whole of the silicic acid will become so entirely saturated with the metals, that no combination will take place when the lime is slaked and made into mortar.

VICAT, who has studied this subject with considerable perseverance, has drawn up a variety of interesting details concerning the effect of heat, &c., upon hydraulic limestones; and from which the annexed particulars are transcribed. In this table, the figures denote the period that elapsed before the cement hardened, which varied according to the amount of carbonic acid contained in it. Thus, when it contained—centesimally—

Carbonic acid.	30	27	26	23	20	10
The mortar hardened in	15 minutes.	12 minutes.	7 minutes.	9 days.	30 days.	9 days.

The several samples of cement upon which these experiments were performed, were obtained from the same variety of limestone.

Hydraulic lime scarcely ever hardens on the first application of water, but only acquires a certain degree of consistence, and then gradually becomes more solid.

As the composition of the cements stands in close relation to the degree of hardness which they assume, it may be well to notice shortly each of the constituents, pointing out at the same time the manner in which they tend to solidify the material.

SILICA, SILICIC OXIDE; *Anhydrous silicic acid* (SiO_2).—Of all the components of cements, except the lime alone, this body is the most important, as the hardening depends upon it. It is met with in two states in rocks and minerals, namely, in the crystalline and the amorphous. Rock-crystal, quartz, the diamond, and many other bodies, contain it in the first condition, whilst opal, flints, and similar compounds contain the amorphous variety. In the crystallized state, silicic acid has very little tendency to act chemically upon bodies in the humid way; but if it be heated to redness with caustic lime or an alkali, then it is brought to the amorphous state, and becomes capable of forming combinations with those bodies. Quartz sand, when mixed with lime, has little value in producing a cement; but if it be first heated with a third of its weight of lime, and then mixed, a considerable difference will be observed in the product. On the contrary, powdered opal, and even precipitated silicic acid, form a tolerably good cement with lime, without heat being applied. It is well known that silicic acid, when freshly precipitated, removes a considerable quantity, if not all of the lime, from its solution in water, a silicate being formed. Such also may be the change which is effected during the hardening of the cements. An excess of silica in the mortar is not, however, desirable, as it does not contribute to its solidity or hardness as much as might at first be supposed; an instance of this fact is, that pitch and pumice-stone, which latter contains from 70 to 80 per cent. of silicic acid, does not make so good a cement as opal and pitch.

ALUMINA.—This earth undoubtedly contributes to the hardening of the cement by combining with part of the calcium set free by the action of the water upon the silicate.

CLAYS.—The clays may be used as substitutes for silicic acid in hydraulic mortars, but being very variable in constitution, it is probable that they operate differently in many samples. To make them as serviceable as possible, they ought to be well burned, as by this treatment their union with lime is greatly facilitated. Many clays, before they will form good cements, must be heated with lime to a very high temperature. This is especially the case with the common ferruginous earths.

MAGNESIA.—When minerals chiefly composed of silicate of magnesium are brought into contact with lime they have no tendency to unite with it, and, therefore, form no cements. If, however, the magnesia is present in excess, as in dolomite, then it contributes to the formation of a powerful mortar. This behaviour of magnesia is owing to the great affinity which exists between it and silica. In the first case, where lime and natural silicate of magnesium are brought into contact, there is no combination, because the silicic acid is united more energetically with the magnesium than it could be with the calcium, and, therefore, no chemical change is produced which might give rise to a silicate of calcium when the powdered mass is mixed with water. But in the case where there is an excess of magnesia, not combined in the natural state with the silicic acid, then, on slaking, the magnesia and silica rapidly unite, and a very firm compound results. Indeed, so powerful is the affinity of silica for magnesia, that the dolomitic limestones always afford a better and more binding compound than if the metal were wholly calcium. Dolomites containing only carbonates of calcium and magnesium, after being burned, will yield a mortar that will set under water; and if silicic acid be present in the proportion of 6 to 10 per cent. or more, a very superior hydraulic mortar results from the formation of a double silicate of magnesium and calcium. Hence, when magnesia is one of the components of the hydraulic lime, and is not combined with the silica in the natural state, the setting of the mortar is afterwards to be attributed in a great measure to this body. The degree of compactness which mortar assumes is, however, to some extent dependent upon the molecular state of the silica, and also upon the amount of the bases combined with it.

ALKALIES.—The alkalies undoubtedly play an important part in giving rise to insoluble silicates during the solidification of the cements. KUHLMANN and others have shown that such minerals as contain alkaline silicates, part with the whole of the alkali to water, after they have been subjected to heat for some time. This is more especially the case if the minerals contain much lime, as then a silicate of calcium and a carbonate or caustic alkali result. It has been observed that many hydraulic limestones containing alkaline silicates, communicate an alkaline reaction and a saponaceous feeling to the water surrounding the mortar during its setting.

It was on this principle of double decomposition being produced by the alkaline silicate, that KUHLMANN recommended the fusion of a quantity of alkali with the inferior varieties of hydraulic lime, for the purpose of enhancing their value. During his investigations on this subject, he observed that there was a larger amount of alkalies present in limestone than was anticipated, and that they had been overlooked in analyses generally, as iodine and bromine were in many waters. He found that a solution of silicate of soda—soluble glass—when filtered through hydrate of lime, loses a portion of its acid, this being taken up by the lime and producing a silicate. The same effect results if sulphate or carbonate of lime be used instead of the hydrate; and if these compounds be taken in large pieces, and immersed in a solution of soluble glass for some time, their surfaces will become so hard from the silicate of lime formed upon them, that they can be highly polished. The depth to which the silicic acid is absorbed is greater according as the immersion is prolonged, till, ultimately, the chalk becomes as hard as stone, being converted into a silicate of the base. From this deportment of the alkaline silicates, it is evident they serve a very important purpose, by yielding their acid to the lime during the setting of the mortar.

Although it is only the sand, the lime, the magnesia, and a few other substances, which take an active part in the solidification, yet the remaining constituents cannot well be said to be inactive; for though the bodies mentioned manifest their action in a striking manner, still, in the course of time, the latter must have some influence in favouring the binding qualities of the cements.

Having thus explained the nature of hydraulic cements, whereby their properties and adaptation to building purposes may be ascertained according to chemical principles, it may now be desirable to allude cursorily to those physical observations from which a good estimation of the value of cements may be formed.

The limestone being burned, with the precautions already pointed out, it is slaked; and from the manner in which it behaves during this process a good idea of its value as a cement may be obtained. If the material contains few insoluble matters, or, in other words, if it be a rich lime, then on immersing it for a few seconds in water, and depositing it upon a trough or other vessel, it will immediately disintegrate more or less, produce a hissing noise, generate heat, by which considerable volumes of vapour are evolved, and ultimately fall into a very fine powder. When the lime is poor, on treating it with water the phenomena observed in the preceding rich lime are not exhibited for five or six minutes; but after this time they begin to be developed with great force.

With lime of very slight or at least of weak hydraulic properties, the slaking does not manifest itself till about a quarter of an hour after the addition of the water, and even then the heat which is evolved is much less than in either of the varieties already mentioned. When the hydraulic properties are more marked, an hour or so may elapse before the lime shows any symptoms of slaking, and then it disintegrates without making any noise, or giving off a hissing sound like the others. If the substance be a very energetic hydraulic, the period of its slaking is very variable, and the usual phenomena are scarcely perceptible. In many cases it cannot be reduced to powder by the action of water, and the heat produced is scarcely sensible to the touch. Those stones which, previous to being burned, consisted almost wholly of carbonate of lime, swell to double their bulk by the action of water upon them after calcination; the poorer kinds of lime increase but very little, or sometimes scarcely at all. If both these limes were disseminated in a sufficient quantity of water, they would be almost entirely dissolved. The other varieties which have *moderate*, *well-marked*, and *energetic* hydraulic properties, increase in bulk not more than the poorer kind just noticed. They set, or harden, on being immersed in water; but in this respect greatly vary. The moderate hydraulics solidify in fifteen or twenty days, and continue to do so for a year, when they have acquired a consistence similar to that of hard soap. Hydraulic limes of well-marked properties set under water in five or six days, their density increasing during a period of six or twelve months. At the end of this time the tenacity is about equal to that of the softer kind of building stone. Water exerts but little action upon them afterwards. The energetic hydraulic limes harden in three or four days after immersion in water, and in six months they assume the induration of compact limestone, so that they are quite unaffected by the action of a stream of water.

The most important cements in general consumption are those known as *Roman* and *Portland* cements. The other varieties have been almost wholly superseded by these valuable building cements. Portland cement is an artificial mixture of chalk and clay, whilst Roman is prepared by burning a natural cement stone. The cements from plaster of Paris are used by decorators.

ROMAN, or more properly PARKER'S CEMENT, is so called after the similar material which the ancient Romans prepared out of a species of porous rock found in the neighbourhood of Puteoli, near Naples, and known at the present time as *puzzolana*. This substance, which has been analyzed by BERTHIER, whose results are appended, is the product of volcanic eruptions:—

	Centesimally represented.
Silica,	44·5
Alumina,	15·0
Lime,	8·8
Magnesia,	4·7
Oxides of iron and titanium,	12·0
Potash,	1·4
Soda,	4·1
Water,	9·2
Loss,	0·3
	100·0

Another variety of this substance has been discovered by Sauvage in the Departement des Ardennes, which does not present any feature to show its volcanic origin. Its composition is—

	Centesimally represented.
Soluble silica—gelatinous,	56·0
Clay,	7·0
Fine quartz sand	17·0
Fine grey limestone—chlorite,	12·0
Water,	8·0
	100·0

This variety occurs below the chalk, resting upon a fossiliferous deposit of clay; it is very soft, and has a pale, greenish colour.

As the Romans extended their sway westward into Germany, they soon found deposits of material similar to that at Puteoli, and to which the name *tarras* or *trass* has been given. So extensive are the beds of this material near Bonn, that the quarries opened there by the Romans have been worked ever since, and the product transmitted to all parts of the country. It is of volcanic origin like puzzolana, and gives indications of being thrown out by the burning mountains of Eifel. A sample of trass from Brohlthal afforded to Elsner the annexed numbers:—

	Centesimally represented. Soluble in Acid.	
Silica,	11·50	
Oxide of iron and traces of manganese,	11·77	
Alumina,	17·70	
Lime,	3·16	
Magnesia,	2·15	
Potash,	0·29	
Soda,	2·44	
		49·01
	Insoluble in Acid.	
Silica,	37·44	
Alumina,	1·25	
Oxide of iron,	0·57	
Lime,	2·25	
Magnesia,	0·27	
Potash,	0·08	
Soda,	1·12	
		42·98
Water with traces of ammonia,		7 65
Loss,		0·36
		100·00

Trass and puzzolana are admirably adapted for the manufacture of cements of hydraulic properties; for, as will be seen by the preceding analyses, they contain a large quantity of amorphous silica which combines with the lime, as well as considerable quantities of alumina and iron which also enter into combination; and besides, the large amount of the alkalies present in them contributes materially, as has been already shown, to the setting of the compound in water. Both these varieties are generally ground by stamping mills to a very fine powder, and then exported. It was for a substitute for this material that Mr. Parker obtained a patent about the year 1796 to produce the *Roman cement.* The substances employed by him were such as still continue to be the basis of this material; they are nodules of an ovoidal or globular form found in the London clay, and known by the term *septaria.* It was thought that these nodules were confined to the few places in which they were then discovered; but as the search for them became more general, they were detected at Harwich, Southend, in the Isles of Wight and Sheppey, and also on the coasts of Kent, Somerset, and Yorkshire, as well as in Flintshire, Calderwood in Scotland, and on the coast of France.

These cements contain about 60 per cent. of calcium or magnesium carbonate, with from 30 to 40 per cent. of clay. They seldom contain alumina or soda, and hence are far inferior to artificial Portland cement. The following table shows the relative quantities of the constituents:—

	Clay. Per cent.		Calcium Carbonate. Per cent.
Parker's cement,	45·0	..	55·0
'Yorkshire,	34·0	..	62·0
Sheppey,	32·0	..	66·0
Harwich,	47·0	..	49·0

Southend cement:—	Per cent
Ferric oxide,	9·0
Silica,	12·0
Alumina,	3·4
Calcium carbonate,	64·0
Magnesia,	1·5

Calderwood cement:—	
Ferrous oxide,	10·2
Silica,	8·8
Alumina,	3·4
Calcium carbonate,	64 0
Magnesium,	2·6

Cement stone is found in the United States, which contains more alumina and less calcium carbonate than the English variety.

The mode of manufacture is very simple, and is that which was originally proposed by Parker. The stones are burnt at the highest temperature possible short of vitrification, the aim of the maker being to get a cement of the lowest possible specific gravity.

In this respect there is a great difference between Roman and Portland cement, since the latter is best when it possesses the greatest weight. A bushel of good Roman cement should weigh about 75 lbs., a bushel of the best Portland cement 140 lbs.

The kiln used is very similar to the common lime kiln. It is generally from 20 to 25 feet high, from 9 to 12 feet wide at the top, and from 7 to 8 feet wide at the bottom. Its internal capacity is between 70 and 80 tons. The stone is broken into pieces from 2 to 3 inches square, and placed in the kiln in layers alternately with a sufficient amount of coal dust to insure its complete decarbonization when burnt. When once lit, the kiln is worked continuously (sometimes for months); the burnt stone being withdrawn at the bottom, and raw supplied at the top of the kiln. The stones are then crushed by stampers and heavy edge stones to a very fine powder, and after removing any coarse fragments by very careful sifting through sieves of about 1600 meshes to the square inch (No. 40 gauge), the powder is packed in casks. The powder readily absorbs carbonic acid and moisture from the air; it hardens very quickly. Medina cement is of the same nature as Roman, except that the septaria employed are those of Hampshire. Mulgrave or ATKINSON's cement is prepared in a similar way from the lias and other species of rock.

Roman cement is at its best when freshly burnt, as it deteriorates rapidly by keeping. Portland cement, on the contrary, keeps well even when exposed to the air. Roman cement will not bear a larger admixture of sand than 1 to 1. For foundations, however, a concrete may be used of 5 to 6 parts of gravel to 1 of cement.

PORTLAND CEMENT.—This artificial cement, which has gained a deservedly great reputation, and is decidedly superior to the others in point of tenacity and durability, is made by intimately mixing chalk and clay.

The relative quantities to be used of each material depends on the amount of calcium carbonate in the rough chalk, and of silica and alumina in the clay. If the clay contains no more than 15 per cent. of iron oxides, 20 parts of clay to 80 parts of chalk is about the correct proportion.

The mixing is performed under water, the greatest care being taken to avoid leaving any lumps of clay and chalk in the mud thus formed. The mixture is then run into large pits, and after prolonged settling the supernatant water pumped off. As much as possible of the remaining water is drained off, after which the mud is dried and burned in proper kilns, ground like the cements just described, sifted, and packed for sale. The process, though inexpensive, is a very slow one, and occupies from two to three months.

Cements of various degrees of setting qualities are manufactured in Germany by calcining clays and limestones in the same way as the foregoing, but much of their power is dependent upon the nature of the clay, and the degree of heat at which calcination is performed. They are, however, for the most part, inferior to those made by the wet way, as well in the property of setting under water, as in the tenacity with which they bind bodies together. The process pursued is such as the following. The raw materials, limestone and clay, or mud, are intimately mixed in equal quantities, the mixture is dried in the air, and then burnt in a shaft oven. A layer of coke alternates with a layer of cement stone. At a white heat the mass becomes grey, with here and there a streak of green; at this stage it must be removed from the oven, as, if the heating be continued the mass becomes blue-grey in colour, and is useless as a cement.

Portland cement sets very quickly when mixed with water to the consistence of a pulp; after a month it becomes so firm and hard as to emit a musical sound when struck by a hard body.

The following are analyses of various samples of Portland cement:—

	1	2	3	4	5
Lime, ...	59·06	62·81	61·64	55·06	57·83
Silica, ...	24·07	23·22	23·00	22·92	23·81
Alumina, ...	6·92	5·27	6·17	8·00	9·38
Oxide of iron, ...	3·41	2·00	2·13	5·46	5·22
Magnesia, ...	0·82	1·14	—	0 77	1·35
Potash, ...	0·73	1·27	—	1·13	0·59
Soda, ...	0·87		—	1·70	0·71
Calcium sulphate, ..	2 85	1·30	1·53	1·75	1·11
Clay, ... Sand, ...	1·47	2·54	1·28	2·27	—

No. 1 and 4 are English Portland cements. No. 2 is a Stettin cement. No. 3 is called Star cement. No. 5 is a cement made at Bonn.

Concrete and *béton* belong to the class of mortars, and are much used in underground works, and in the foundations of large edifices. They also serve as a backing for walls of great thickness. They are prepared by mixing coarse gravel and fragments of stone with lime, which may or may not have been previously worked up into mortar.

For water-works, where it is necessary that the compound should set rapidly, a mixture of hydraulic lime, puzzolana, and sand, may be used in the annexed proportion, recommended by TREUSSART:—

30 parts of strong hydraulic lime measured in bulk before being slaked,
30 do. of trass,
20 do. of gravel,
30 do. of sand, and
40 do. of hard limestone broken.

These materials diminish one-fifth after being worked up. The stones and gravel are added after the sand and lime have been mixed up into a mortar. This cement should be used immediately after it is made. When the puzzolana is used, the proportions taken are:—

32 parts of strong hydraulic lime measured before slaking,
44 do. of puzzolana,
22 do of sand,
60 do. of broken stone and gravel.

This concrete is exposed for twelve hours before it is used.

For river and sea works a concrete similar to the above, and answering the required purpose very well, is manufactured by mixing a mortar made of three parts of quartz sand, and one of unslaked hydraulic lime, with an equal weight of gravel or broken stones. No water should be added to the mixture during the time the mortar is being incorporated with the stones and gravel.

If the latter have a smooth surface, they are not so well adapted for the preparation of concretes of this description, as when they are angular and pointed. Granite clippings and other fragments are very eligible for this kind of mortar. Much difference exists between the behaviour of concrete and that of béton in water, for the former does not set, and therefore is acted upon by the water, if not protected, whilst the latter is eminently hydraulic.

COIGNET'S CONCRETE.—Sand is mixed with one-fourth its weight of lime and one-twentieth its weight of Portland cement. A very small quantity of water is then added, and the whole ground in a mortar mill till a pulverulent paste is obtained, which on further grinding becomes a firm plastic mass. The mixture is then ready for the mould, into which it is introduced in thin layers and powerfully rammed until its bulk is reduced one-third. A few days, sometimes a few hours, suffice to convert the whole into a hard stonelike mass. Buildings made with this material are practically homogeneous, since the work of one day unites without visible join with that of the preceding.

DECORATOR'S CEMENTS, such as KEENE'S, MARTIN'S, Parian, &c., have gypsum or plaster of Paris for their basis instead of a hydraulic lime. The method of preparation is almost the same in all.

Gypsum differs from those substances hitherto considered, as well in its chemical constitution as in its behaviour as a cement. The several mortars and cements already described owe their property to the formation of a silicate during the setting, but in the case of gypsum or plaster of Paris no such combination takes place; indeed, its hardening properties are rather diminished than enhanced by admixtures of caustic lime or silica.

The induration of gypsum is, however, to be attributed to a union of another kind, namely, of water. Gypsum, or sulphate of lime, when exposed to the air for a length of time, will not set when mixed with water in the usual way, because the necessary amount of constitutional water for the formation of the crystallized salt had been absorbed from the atmosphere. If this substance were, however, exposed to a high temperature, sufficient to expel all the moisture with which it united, and the dry powder blended with water, it would readily harden. The gypsum, in this case, unites with about a fourth of its weight of water, by which it is rendered crystalline; but besides this amount it is capable of enveloping or solidifying a much larger quantity. By reason of this behaviour, gypsum forms a solid mass with as much as its own weight of water. With such an amount, however, it never acquires much tenacity, but, upon the evaporation of the excess, the portion of the salt which was dissolved assumes the crystalline form and binds the solid particles more firmly together. This property of gypsum makes it very valuable for many architectural and artistic purposes, but only those connected with cements will here be alluded to. The setting of gypsum depends upon the production of the crystalline hydrate, $CaSO_4.2H_2O$. By examining the wet mass of burned gypsum and water under a microscope, this process of crystallization becomes evident. As ordinary burned gypsum contains about 8 per cent. of water, an addition of only 12 per cent. is necessary for the formation of the solid hydrate. In practice as much as 33 per cent. of water is often added, as it is found that unless the mass be semi-fluid it hardens too quickly. The cement thus produced is porous, and is rapidly acted on by the atmosphere with the production of nitrate of calcium. The addition of such substances as gum, gelatine, glycerine, &c., delays the crystallization, and hence diminishes the rapidity of setting of gypsum; such bodies may therefore be employed for this end, a smaller percentage of water being added.

Sulphate of calcium, when set by water, never acquires the tenacity of stone; it always remains soft, so that it may be easily scratched by the nail. This softness was a great impediment to the execution of several works in plaster, and for a long time a remedy was sought, with only partial success. Various suggestions and prescriptions were offered, most of which were unavailing. GAY-LUSSAC first observed that the hardest natural gypsum also yields the firmest product after setting in the usual manner.

The proposition of hardening gypsum by means of a solution of alum was first made by PAUWARE, and carried out with modifications by several persons; and this has proved the best, or one among the best and readiest means by which tenacity may be communicated. The alum solution used contains 20 ozs. of alum to 6 lbs. of water. Other salts in solution are capable of effecting the same change, some by a double decomposition being induced; thus gypsum and bitartrate of potash give tartar and crystallized gypsum; whilst with others the theory of the induration by their means is not so easily demonstrated. The hardening with alum is accounted for by the fact that sulphate of lime is capable of combining with another salt forming a binary compound, in the same way as sulphate of magnesia unites with other sulphates; thus gypsum and potash alum form a double sulphate, having the formula $CaSO_4 + K_2SO_4 + H_2O$. It is of this behaviour of gypsum with solutions of salts that advantage has been taken, and patents secured for manufacturing the cements noted above.

KEENE'S cement is made by mixing the powdered gypsum with a solution of alum, and then baking the compound at a temperature approaching dull redness, so as to dissipate the whole of the combined water. The mixture is again powdered by stampers, or ground under edge stones. When used the powder is slaked by a solution of alum in 12 or 13 parts of water. Common water might here be employed, but that hardness which is given by the alum liquor could not be attained.

MARTIN'S composition is made in the same way as the one just described, only that carbonate of soda, or carbonate of potash, is employed as well as the alum, and the burning takes place at a higher temperature.

Parian cement is prepared by using a lye of borax containing 1 part of borax and 9 parts of water, instead of the forementioned. These varieties are very useful for floorings, skirtings, &c., and especially where damp and vermin have to be guarded against. These materials, like stucco, may be employed in cementing walls, and their surface can be embellished with various artistic delineations similar to fresco-painting.

Stucco is a compound of powdered gypsum and a solution of glue or strong gelatine, which is employed to coat walls, and also for ornamenting ceilings, and other works of art. It is capable of receiving a high polish, and also of taking designs in colour. When employed on walls, the coarser kind is first laid on, and an outer coating of a finer preparation of gypsum and glue, or isinglass, afterwards deposited upon it, and when dry, polished with pumice, tripoli, and linen rubbers. The colour is incorporated with the outer coatings of the stucco, by mixing the metallic pigments with it, and then applying it to the wall, after which a very thin coating of gypsum and isinglass, or sometimes of oil, is given; and when the whole is partially dried, the tint is brought out by polishing, as before stated. Generally, the finest is given with oil.

A very good hydraulic mortar is made by slaking lime with water containing about 2 per cent. of gypsum, and adding a little sand to the product. The presence of the gypsum tends to delay the slaking of the lime, and also to harden the substance formed after the slaking. If water containing a little lime in solution be added to burnt gypsum, a very hard compact mass is obtained: this substance is much used as an imitation marble, as by polishing it with pumice stone, colouring it, and again polishing with oil, it may be made to resemble natural marble very closely. Hardened gypsum treated with stearic acid or paraffin and polished, is used as a substitute for meerschaum, which it much resembles.

Mosaics.—The processes of forming patterns and devices by the cementation of several pieces of coloured and other substances, is one exhibiting great art and skill. The ancient Romans excelled in this, as is evidenced by the fragments of pavements and other remains which have been discovered in the various countries they subdued. Rome and Florence still continue pre-eminent in this kind of work; but instead of it being, as of old, exclusively used to decorate walls and floors of buildings, it is now employed by artists for copying the most delicate paintings, the material for this purpose being a kind of very fusible enamel, tinged by metallic oxides. This constitutes the surface of the picture, being supported on a ground of very hard cement. It is said that no less than 1,700,000 pieces of this composition entered into the construction of a portrait of one of the popes, exhibited at the International Exhibition of 1851.

The following processes for preparing mortars and hydraulic cements which are used by the Turks, may be interesting:—

Ordinary mortar is prepared by mixing 2 parts of powdered lime, and 1 of river sand, with the necessary quantity of fresh water.

Hydraulic mortar.—Bricks are triturated till their powder appears of the fineness of common river sand; 1 part of this is afterwards mixed with 2 parts of fine lime, and the necessary quantity of fresh water. When using this mortar, it is laid between the bricks, or courses of bricks, in layers as thick as the latter. To render it very binding, the bricks are allowed to remain in water till they become saturated. When the mortar is used for the internal dressing of arches, aqueducts, large cisterns, or reservoirs, baths, &c., it is made in the following manner:—

250 lbs. of milk of lime, and 220 lbs. of extremely fine plucked tow, are to be mixed together very intimately and regularly. The whole is allowed to stand for eight days, that the lime and tow may form a thorough combination. Before being used, it is well stirred up. It is laid on in the usual way, by means of a small trowel, and afterwards subjected to the dressing, which consists in a prolonged rubbing with the trowel, till the surface is smooth and even. To render the cement unaffected by water and more durable, it is covered with a layer of the following composition:—

250 lbs. of fresh burned lime slaked,
62 lbs. of linseed oil, and about,
2 ozs. of rough cotton.

The lime is mixed with the oil and cotton in successive portions, till the mass has the consistency of dough. It is then moulded into square blocks and preserved for use. Before being applied, it is stirred up with linseed oil to bring it to the thickness of a stiff paste.

CHLORAL AND CHLOROFORM. Chloral (C_2HCl_3O).—This compound was discovered in 1832 by Liebig (*Ann. Chem. Pharm.*, vol. i. p. 189) whilst studying the action of chlorine on dry alcohol, and was subsequently investigated by Dumas (*Ann. Chim. Phys.* [2], vol. lvi. p. 123), and by Staedeler (*Ann. Chem. Pharm.*, vol. lxi. p. 101).

Preparation.—On passing pure and dry chlorine into well cooled absolute alcohol, the gas is absorbed with the greatest avidity at first, but after a time the action becomes less powerful, and the liquid assumes a yellow tint. It must then be gradually heated, ultimately raising the temperature to near the boiling point, whilst a rapid current of chlorine is still passed into the liquid. During the whole of the operation large quantities of hydrochloric acid are given off, and also much ethyl chloride; the latter being produced by the action of the hydrochloric acid on the unaltered alcohol.

After the liquid is saturated with chlorine, which takes about twenty hours for 8 ozs. of alcohol, the thick oily product, if put aside for a few days in a cool place, solidifies to a crystalline mass of impure chloral alcoholate. In order to obtain pure chloral from this, it must be fused and agitated with four or five times its bulk of concentrated sulphuric acid for a few minutes. On allowing the mixture to stand the anhydrous chloral rises to the surface as an oily layer, which must be removed as quickly as possible, for prolonged contact with the acid would convert it into the insoluble metachloral. It is then rectified over lime, which has been slaked and subsequently ignited, in order to remove hydrochloric acid, but care must be taken that none of the lime rises above the surface of the liquid, as it will otherwise decompose the vapour and become red-hot. In this manner the chloral is obtained tolerably pure, but it still contains traces of water and of alcohol, which may be removed by another treatment with sulphuric acid and subsequent rectification over lime.

Staedeler also obtained chloral by distilling 1 part of starch or grape sugar with 7 of hydrochloric acid, and 3 of peroxide of manganese, adding a little common salt to neutralize the injurious effect of the sulphuric acid produced from the sulphurous anhydride which usually occurs in commercial hydrochloric acid. The aqueous distillate, separated from the oily drops, is saturated with salt and repeatedly redistilled, carefully removing the oil each time. The concentrated aqueous solution of chloral is then saturated with dry chloride of calcium, and distilled in an oil bath at 120° C. Hydrate of chloral passes over as a colourless liquid, which solidifies in the receiver to a crystalline mass.

It might be imagined that the action of chlorine on alcohol was a very simple one, being merely the removal of two atoms of hydrogen and the replacement of three of the remaining atoms by chlorine, forming chloral, thus:—

$$\overset{\text{Alcohol.}}{C_2H_6O} + Cl_2 = \overset{\text{Aldehyde.}}{C_2H_4O} + 2HCl,$$

and that the nascent aldehyde is then transformed into chloral—

$$\overset{\text{Aldehyde.}}{C_2H_4O} + 3Cl_2 = \overset{\text{Chloral.}}{C_2HCl_3O} + 3HCl.$$

From the elaborate researches of Wurtz and Vogt (*Compt. Rend.*, vol. lxxiv. p. 777), however, it would seem to be much more complicated; the first action of the chlorine on the alcohol is indeed, as above represented, to remove two of the hydrogen, forming aldehyde:—

$$\overset{\text{Alcohol.}}{CH_3.CH_2.OH} + Cl_2 = \overset{\text{Aldehyde.}}{CH_3.COH} + 2HCl.$$

The hydrochloric acid then acting on this aldehyde and on the excess of alcohol forms monochlorether:—

$$\overset{\text{Aldehyde.}}{CH_3.CHO} + \overset{\text{Alcohol.}}{C_2H_5.OH} + HCl = \overset{\text{Monochlorether.}}{CH_3.CHCl(OC_2H_5)} + OH_2.$$

The monochlorether is then converted into tetrachlorether by the continued action of the chlorine—

$$\overset{\text{Monochlorether.}}{CH_3.CHCl(OC_2H_5)} + 3Cl_2 = \overset{\text{Tetrachlorether.}}{CCl_3.CHCl(OC_2H_5)} + 3HCl,$$

and this, by the action of water, splits up into alcohol, hydrochloric acid, and chloral, thus:—

$$\overset{\text{Tetrachlorether.}}{CCl_3.CHCl(OC_2H_5)} + OH_2 = \overset{\text{Chloral.}}{CCl_3.CHO} + HCl + \overset{\text{Alcohol.}}{C_2H_5.OH};$$

or, as the final result of the action of chlorine on alcohol is not chloral but chloral alcoholate, the last reaction may take place thus:—

$$\overset{\text{Tetrachlorether.}}{CCl_3.CHCl(OC_2H_5)} + OH_2 = \overset{\text{Chloral Alcoholate.}}{CCl_3.CH(OH)(OC_2H_5)} + HCl.$$

It must be stated, however, that although the action of chlorine on a mixture of aldehyde and concentrated hydrochloric acid appears to produce some chloral hydrate, the principal products are dichloraldehyde and crotonic chloral.

Lieben, on the other hand, considers the formation of the chloral alcoholate from alcohol to take place in a different manner. In 1857 he showed that the action of chlorine on alcohol at ordinary temperatures gave rise to mono, di, and tri-chloracetal, and Paterno, in reinvestigating the subject, found that at 80° C. the higher chlorinated derivative is formed in considerable quantity. This is a solid crystalline substance, which by the action of concentrated sulphuric acid appears to give chloral, although Paterno and Pisati's experiments are not quite conclusive on that point. An isomeric liquid modification of trichloracetal is formed on heating tetrachlorether with alcohol in the manner shown in the following equation:—

$$\overset{\text{Tetrachlorether.}}{CCl_3.CHCl(OC_2H_5)} + \overset{\text{Alcohol.}}{C_2H_5.OH} = \overset{\text{Trichloracetal.}}{CCl_3.CH(OC_2H_5)_2} + HCl;$$

and this compound, according to Wurtz and Vogt, when heated with water or sulphuric acid, yields alcohol and chloral,

$$\overset{\text{Trichloracetal.}}{CCl_3.CH(OC_2H_5)_2} + OH_2 = \overset{\text{Chloral.}}{CCl_3.CHO} + \overset{\text{Alcohol.}}{2C_2H_5.OH};$$

or chloral alcoholate and ethyl chloride may be simultaneously formed from it by the action of hydrochloric acid, thus:—

$$\overset{\text{Trichloracetal.}}{CCl_3.CH(OC_2H_5)_2} + HCl = \overset{\text{Chloral Alcoholate.}}{CCl_3.CH(OH)(OC_2H_5)} + \overset{\text{Ethyl Chloride.}}{C_2H_5Cl}.$$

It will thus be seen that the difference between the two hypotheses is really as to whether the tetrachlorether which is formed splits up at once in contact with water into alcohol, hydrochloric acid, and chloral, or as to whether it is first converted into the liquid modification of trichloracetal by double decomposition with alcohol, and that the trichloracetal is then decomposed by water, or by hydrochloric acid, with formation of chloral and alcohol, or chloral alcoholate and ethyl chloride. Whatever may be the series of reactions which takes place, it is certain that the final product is chloral alcoholate.

In the action of chlorine on alcohol, hydrochloric acid is produced; and this by a secondary reaction on the excess of alcohol gives rise to large quantities of ethyl chloride, part of which escapes, and part is converted by the chlorine into ethylidene chloride.

Properties.—Anhydrous chloral, C_2HCl_3O or $CCl_3.COH$, is a thin oily liquid, of density 1·502 at 18° C., and according to Kopp boils at 98°·6 C. It has a peculiar pungent odour. Chloral is readily soluble in ether, and when mixed with a small quantity of water or alcohol solidifies to a mass of crystals of the hydrate or alcoholate. When kept for some time, or when placed in contact with concentrated sulphuric acid, it is converted into a metameric compound ($C_6H_3Cl_9O_3$) called metachloral. In the latter process of transformation it is accompanied by a little chloralide, from which it may be freed by pulverising it and washing it with alcohol. Aqueous solutions of the alkalies readily decompose chloral with formation of chloroform and potassium formate:—

$$\overset{\text{Chloral.}}{CCl_3.CHO} + KHO = \overset{\text{Chloroform.}}{CHCl_3} + \overset{\text{Potassium Formate.}}{CHO.KO}.$$

In fact, this is the best method known of preparing absolutely pure chloroform. When heated with alcoholic potash, chloroform and ethyl formate are produced, the reaction taking place wholly between the alcohol and the choral—

$$\overset{\text{Chloral.}}{CCl_3.CHO} + \overset{\text{Alcohol.}}{C_2H_5.OH} = \overset{\text{Chloroform.}}{CHCl_3} + \overset{\text{Ethyl Formate.}}{CHO.C_2H_5O.}$$

Alcohol alone, however, does not effect this decomposition.

Chloral is converted into aldehyde by the action of nascent hydrogen, as when it is treated with zinc and dilute sulphuric acid, the 3 atoms of chlorine being replaced by hydrogen. Chloral, or its hydrate, when boiled for some time with nitric acid is decomposed, giving rise to chloropicrin, CCl_3NO_2; but at the ordinary temperature trichloracetic acid is produced. By far the most convenient method of preparing this acid, in fact, consists in exposing a mixture of chloral hydrate with three times its weight of fuming nitric acid to the sunshine for three or four days, and then distilling the mixture. At 195° C. pure trichloracetic acid comes over.

Chloral, when treated with different reagents, undergoes numerous and varied decompositions, but as these are purely of scientific interest, we must refer our readers for a full account of them to Watts' "Dictionary of Chemistry," 2nd Supp., p. 308, *et seq.*

Chloral unites directly with various substances, but the only compounds of any technical interest are the hydrate and alcoholate.

Chloral Alcoholate, $C_4H_7Cl_3O_2$, or $CCl_3.CH(OC_2H_5)(OH)$, may be obtained in a pure state by mixing the equivalent quantities of anhydrous chloral and absolute alcohol. The two substances combine with the evolution of much heat, and on standing solidify to a crystalline mass, which, according to Lieben, melts at 43° to 46° C. and boils at 115° C. (113°·5 corr., according to Jungfleisch, Lebaigne, and Roucher). As previously noticed, chloral alcoholate is the ultimate product of the action of chlorine on alcohol. On passing carefully dried chlorine into alcohol until its weight has been doubled, and allowing the product to cool, it solidifies to a crystalline mass, which was thought by Roussin to be chloral hydrate, but has since been proved to be chloral alcoholate. It differs from the hydrate in many respects, as according to Roussin it melts at 46° C. and boils at 115° C. Its behaviour, moreover, when gently heated with nitric acid of specific gravity 1·2, serves readily to distinguish the alcoholate from the hydrate. The former undergoes violent decomposition, whilst the latter is scarcely acted on: the alcholate also is readily soluble in cold chloroform, whilst the hydrate is not.

Chloral Hydrate, $C_2H_3Cl_3O_2$, or $CCl_3.CH(OH)_2$, is readily prepared by a process similar to that employed for the alcoholate, namely, by mixing chloral and water in equivalent proportions. The mixture becomes heated and solidifies to a mass of crystals of the hydrate. These are soluble in a larger quantity of water, but the solution when evaporated *in vacuo* over concentrated sulphuric acid deposits the hydrate again in large rhombic plates. According to Flückiger, it crystallizes in splendid flat tables from warm oil of turpentine; but the best method of purifying it is to recrystallize it from pure boiling bisulphide of carbon, which takes up about 20 per cent. of its weight. On cooling, the greater portion is deposited in beautiful, transparent, oblique rhombic prisms, which, after being exposed to the air to allow the adhering bisulphide to evaporate, boil at 97°·5. The hydrate when dissolved in water produces a considerable fall of temperature. Many organic bases, such as quinine, cinchonine, strychnine, aconitine, and atropine, dissolve in a concentrated aqueous solution of chloral hydrate. It also dissolves camphor and phenol.

Manufacture.—Chloral is always manufactured by passing chlorine into alcohol, but the details of the process and of the methods adopted for its purification and conversion into the crystalline hydrate vary to some extent. An excellent result is obtained by passing a rapid stream of chlorine into 120 to 150 lbs. of alcohol, of at least 96 per cent., contained in a large stoneware vessel. The current of gas must be continued day and night without intermission, until the temperature of the chlorinated alcohol has risen to from 60° to 75° C., and its density is 41° Baumé. The product is now transferred to a copper vessel lined with lead, capable of holding 30 to 40 gallons, and an equal weight of concentrated sulphuric acid gradually added. If the mixture be now heated to boiling, hydrochloric acid is copiously evolved, whilst the chloral condenses in the cohobator adapted to the head of the copper vessel and flows back again. The application of heat is continued as long as hydrochloric acid is evolved, which usually continues for seven or eight hours. By this means the chloral alcoholate and other impurities are completely decomposed or destroyed. The cohobator is now replaced by a bent tube fitted with a thermometer, and connected with a worm in order to distil off the purified chloral. When the temperature, which is at first 95° C., rises to 100° C., the distillation is interrupted, all the chloral having passed over. The small amount of free hydrochloric acid still present in it is now neutralized with chalk, and the chloral submitted to a final rectification. In order to convert it into the hydrate 17½ ounces of distilled water are added to each 9 lbs. of pure chloral, and the mixture agitated, taking care to cool during the operation. The still fluid hydrate may now be poured into shallow earthenware dishes, where in the course of half an hour it solidifies into thin cakes, or it may be crystallized from chloroform. For this purpose it is mixed with about half its bulk of chloroform, and put aside in a cool place. In eight or ten days, when the crystallization is complete, the crystals are freed from the mother liquor by a centrifugal machine, and dried at a gentle heat. The mother liquor may be used for crystallizing fresh quantities of the hydrate.

Chloral hydrate was introduced by Liebreich as an anæsthetic and hypnotic, and is now very extensively used in medicine, enormous quantities being manufactured for that purpose, especially in Germany.

Valuation of Chloral Hydrate.—As the specimens of chloral hydrate met with in commerce vary to a considerable extent in the actual amount of chloral they contain, it becomes important to have a simple and accurate method of determining their value. Several processes have been proposed for this purpose; those usually employed consisting in decomposing the chloral by ammonia or a fixed alkali. WOOD recommends for this purpose distilling it with water and milk of lime, and collecting and weighing the chloroform which comes over after separating it from the water. The amount of pure chloral in any specimen of chloral hydrate may also be easily determined by taking advantage of the readiness with which it is decomposed in the cold by an aqueous solution of potassium hydrate. For this purpose 25 grammes of the chloral hydrate under examination are introduced into a tube graduated to $\frac{1}{10}$ cubic centimètres, and then a solution of potassium hydrate is gradually and cautiously added, in quantity rather more than sufficient to decompose the product, supposing it to be the pure hydrate. Whilst the alkali is being added, the tube must be well cooled, as the action is violent at first. As soon as it has somewhat subsided, the decomposition may be completed by gently inclining and finally shaking the tube. In the course of an hour or two the liquid will become clear and separate into two layers. That at the bottom is the chloroform, which can be measured and the percentage of chloroform calculated from its known specific gravity, due regard being paid to the temperature.

The decomposition of the chloral by alkalies does not, however, give perfectly accurate results, as chloroform is not only slightly soluble in water, but also takes up water. VERSMANN, for this reason, prefers to decompose the chloral hydrate with sulphuric acid: 5 or 6 c.c. of concentrated sulphuric acid are introduced into a graduated tube capable of being closed with an accurately fitting stopper, and heated by immersing it in water at 60° C.; 10 grammes of the chloral hydrate are then added, the whole well shaken, and put back into the hot water for a few minutes. The decomposition is immediate, and as soon as the tube has been taken out and allowed to cool, the amount of pure chloral which floats on the acid may be read off. In comparative experiments, somewhat higher results are obtainable by this method than when the amount of chloral is estimated from the chloroform produced.

CHLOROFORM, *Trichloromethane*, or methenyl chloride ($CHCl_3$) (French *Chloroforme*).—This compound was discovered by LIEBIG in the year 1830, whilst studying the products which are formed by the action of chlorine on alcohol, and independently by SOUBEIRAN a short time afterwards. The latter obtained it by the action of chloride of lime on alcohol, and although it is now almost invariably prepared on the large scale by this method, it is also formed in many other chemical reactions: for instance, by the action of chlorine on marsh gas, and on gaseous methyl chloride; when chloral or trichloracetic acid is treated with an alkali; and by the action of chloride of lime on amylic alcohol, acetone, oil of turpentine, acetic acid, tartaric acid, and phenol.

Chloroform may easily be prepared on a small scale by SIMERLING'S process. This consists in distilling in a retort, whose capacity should be at least twice the bulk of the materials, a mixture of eight parts of good chloride of lime, one of quick lime, forty of water, and one of alcohol. A gentle heat should be applied, and the chloroform which comes over separated from the supernatant layer of water. It should then be agitated with concentrated sulphuric acid, and rectified. The weight of the chloroform obtained is nearly equal to one-third of that of the alcohol employed.

When perfectly pure, chloroform is a colourless limpid liquid, which refracts light strongly, and has a peculiar pleasant odour and sweet somewhat burning taste. According to REGNAULT its specific gravity at 17° C. is 1·491, and it boils at 70°. It does not ignite on the application of a light, but when mixed with alcohol it burns with a smoky flame, edged with green. It is only very slightly soluble in water, but imparts to it a sweet taste. It is soluble in all proportions in alcohol and ether.

Chloroform, having the above specific gravity, has a very remarkable peculiarity, namely, that the addition of one, two, three, four, or five per cent. of alcohol renders it opaline; if the proportion is augmented to ten per cent. it again becomes perfectly limpid, but at the same time the density is considerably diminished. Many organic bases, camphor, caoutchouc, wax, amber, copal, and all the common *resins* readily dissolve in it. With black and red sealing-wax it makes a strong varnish. It dissolves sulphur and phosphorus slightly, iodine and bromine more freely, forming deep-red solutions; it coagulates albumen; it floats on concentrated sulphuric acid, which is only darkened by it at a boiling heat. Nitric acid very slowly decomposes it in the cold, but if the temperature is raised, it is oxidized with evolution of nitrous fumes. When chloroform is heated with an alkaline cupric solution, such as is obtained by adding caustic potash in slight excess to a solution of cupric sulphate and potassic tartrate, a precipitate of cuprous oxide is formed. This reaction is very delicate, but the most characteristic and sensitive test for chloroform is the formation of phenyl carbamine, $C_6H_5.CN$, as proposed by HOFMANN. If a little aniline and an excess of an alcoholic solution of potassic hydrate are added to a liquid in which even a mere trace of chloroform is present, and the mixture gently heated, the peculiar penetrating odour of the carbamine will be at once perceived. Of course compounds which, like chloral, are decomposed by an alkali with formation of chloroform, give the same reaction. It has no bleaching properties; it does not affect iodide of potassium, nor does it dissolve gold, either *per se* or when boiled with concentrated nitric acid. Nitrate of silver occasions no precipitate with an alcoholic solution of chloroform. It leaves intact chloride of gold, even when boiled with it.

The vapour of chloroform, passed over copper or iron heated to redness, is decomposed, giving rise to a metallic chloride and a deposition of carbon: according to BERTHOLLET acetylene, C_2H_2, is simultaneously produced. Pure chloroform can be distilled off potassium or sodium without change, but when the metal is heated in the vapour, decomposition takes place with explosive violence. It is scarcely decomposed by boiling with an aqueous solution of potassic or sodic hydrate; an alcoholic solution, however, acts quickly, a formate and chloride of the alkali metal being obtained,

$$\overset{\text{Chloroform.}}{CHCl_3} + 4\,KHO = \overset{\text{Potassic formate.}}{CHO.KO} + 3\,KCl + 2\,OH_2.$$

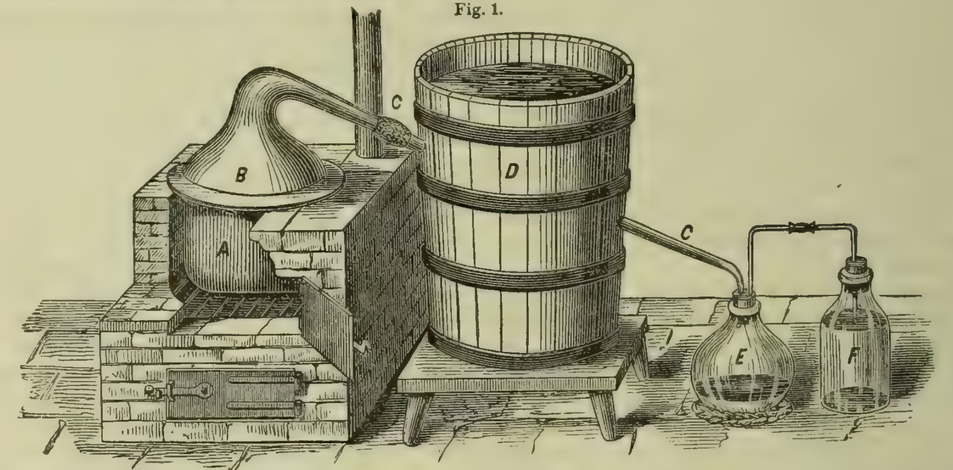
When chloroform, $CHCl_3$, is heated in a current of chlorine, in sunlight, or is treated with iodine chloride, or with antimonic pentachloride, the last atom of hydrogen is replaced by chlorine, and carbon tetrachloride or tetrachloromethane, CCl_4, is formed.

According to PERKIN, when an alcoholic solution of chloroform is agitated with zinc powder and a little ammonia, the chloroform is reduced, and METHYLENE DICHLORIDE, CH_2Cl_2, is found amongst the products; it may be separated by fractional distillation. This compound is also produced by treating methylene di-iodide with chlorine, and along with chloroform and carbon tetrachloride, when chlorine acts on methylic chloride in sunshine. (PERKIN, *Jour. Chem. Soc.*, xxii. 260, and *Chem. News*, xviii. 106). It is a colourless liquid, having an odour similar to that of chloroform, and a burning taste. It boils at about 40° C., and its density at 0° is 1·3604. It has been proposed as an anæsthetic agent, but has not come into general use.

Chloroform, $CHCl_3$, may be regarded as methane or marsh gas, CH_4, in which three atoms of the hydrogen have been replaced by chlorine. Its composition is the following:—

C	= 12	10·04
H	= 1	0·84
Cl_3	= 106·5	89·12
	119·5	100·00

Fig. 1.



MANUFACTURE.—Chloroform is almost universally prepared on the large scale by heating chloride of lime with alcohol, but the details of the process vary considerably. The following are some of the best known methods for the manufacture of this substance:—

1. 130 lbs. of chloride of lime (bleaching powder) and 7 lbs. of ordinary lime, with sufficient water to form a paste, are introduced into a capacious alembic of common earthenware. When well stirred together, more water is added, with 25 lbs. of rectified spirit of wine. Care must be taken that the still is not more than half full; after the head is well luted, a gentle steam heat is applied, and the chloroform distils over along with a little dilute alcohol.

2. 100 lbs. of fresh chloride of lime are thoroughly mixed with 40 gallons of water, so as to form a thin cream, and then introduced into the still, A, Fig. 1, which it should not more than half fill; 12½ lbs. of 90 per cent. alcohol are now poured in, and the head, B, luted firmly on and connected air-tight with the worm, C C, the other end of which passes into the receiver, E. After allowing the apparatus to remain for twelve hours, the retort is gently heated; a powerful reaction soon commences, which requires careful watching at first, for if too great heat be applied, the contents of the retort may boil over. As soon, however, as it has somewhat subsided and the chloroform ceases to come over rapidly, the heat should be increased until the liquid boils, and nothing but water distils. The whole operation requires about four or five hours, and yields 7 lbs. of crude chloroform. This is mostly in the receiver, E, a small portion only being found at the bottom of the bottle, F, which is three parts filled with cold water.

3. In KESSLER'S method, 80 lbs. of the strongest chloride of lime are introduced into a large leaden cylinder through an opening in the top, by means of a square wooden funnel, provided near its lower extremity with a pair of horizontal rollers; these when turned serve to drive the chloride quickly into the still. 8 lbs. of slaked lime are then introduced in a similar manner, and afterwards 20 gallons of water, at a temperature of 90° C. The apparatus is now carefully luted, and the contents

well mixed by means of a revolving fan fixed in the interior of the cylinder. When the contents are thoroughly incorporated, 8 lbs. of alcohol are poured in through an opening provided for that purpose, together with the residues of former operations, and if the action does not immediately commence, steam is blown in by means of a pipe reaching to the bottom of the still. As soon as the chloroform begins to distil the steam is shut off, but is again admitted when the action slackens, the mixture being well stirred by means of the fan. When about 5 pints have been distilled over, no appreciable amount of chloroform remains in the retort.

The chloroform obtained by any of the above processes, after being separated from the supernatant layer, is washed several times with a dilute solution of sodic carbonate, and then distilled once or twice off concentrated sulphuric acid. The aqueous liquid separated from the chloroform contains alcohol, and should be employed, along with fresh alcohol, in a future operation.

4. A very pure chloroform is now manufactured from chloral by decomposing it with an alkali. Chloroform is scarcely acted on by an aqueous alkaline solution, whilst chloral readily splits up under these circumstances, producing chloroform and an alkaline formate ;

$$\underset{\text{Chloral.}}{C_2HCl_3O_2} + \underset{\text{Potassic hydrate.}}{KHO} = \underset{\text{Chloroform.}}{CHCl_3} + \underset{\text{Potassic formate.}}{CHO.KO} + OH_2.$$

If, therefore, chloral hydrate is heated with a dilute solution of potash or soda, it is decomposed in the manner just pointed out, and the chloroform distils over, accompanied by a little water. After being separated from the latter, and distilled off concentrated sulphuric acid, it is perfectly pure.

For the introduction of chloroform as an anæsthetic agent, mankind is indebted to Dr. Simpson of Edinburgh ; great care, of course, must be taken to insure its purity, for the oils which accompany it when first formed are very injurious. In administering it, some person should be especially appointed to watch the pulse and respiration of the patient, and remove the chloroform if necessary ; but it should never be employed in cases where there is disease of the heart, or a marked tendency to apoplexy. Doubtless many accidents and even deaths occur, not from the effects of the chloroform itself, but from the poisonous action of the deleterious oils and other adventitious matters contained in that which is sold. Although this source of danger might be entirely avoided by employing chloroform prepared from chloral, yet medical men ought to exercise caution in administering to sufferers even the purest preparation.

Adulteration.—It is to be deplored that a substance of so much value as chloroform should, in many instances, be rendered positively dangerous or even fatal, by the presence of impurities that might be easily avoided in the first instance, or subsequently removed, but which contaminate it, sometimes to such an extent as to render it either inefficacious for good, or most deleterious when administered.

The foreign ingredients most frequently met with are alcohol, aldehyde, hydrochloric and hypochlorous acids, and chlorinated oils. The latter are exceedingly poisonous in their action ; and, moreover, there is considerable difficulty in discovering their presence, and in freeing chloroform from them. Alcohol may be detected by adding one or two crystals of chromic acid to two drachms of the suspected liquid ; should it be present, the chromic acid is soon reduced to the state of the green sesquioxide of chromium. The same result is obtained by adding a little bichromate of potassa and sulphuric acid, instead of the chromic acid.

Besnou gives the following as the best method of applying this test :—He takes a few milligrammes of powdered bichromate, and puts it into a test tube five or six inches long, and rather more than half an inch in diameter ; he next adds four or five drops of concentrated sulphuric acid, and stirs with a glass rod until the chromic acid is liberated ; then adds three or four drops of water, to dissolve the chromic acid ; and lastly, pours in three or four centimètres of chloroform—one, to one and a half inch cubic measure—shakes quickly for twenty seconds, and leaves the whole to repose ; very soon the deep green colour of the chloride of chromium appears, if the proportion of alcohol amounts to five per cent., and is deposited in a distinct layer at the bottom, whereas the upper part is barely coloured a very pale green. *If the chloroform be pure, the mass is scarcely tinged of a greenish yellow, and there is no separation of any layer.* If it has been adulterated with ether, the results are precisely similar.

Roussin has proposed to use dinitrosulphide of iron as a test for the presence of alcohol, ether, or wood spirit in chloroform ; if any of these impurities are present it acquires a dark colour, but remains colourless if pure. Dinitrosulphide of iron is prepared by slowly adding ferric sulphate to a boiling mixture of ammonic sulphide and potassic nitrite, as long as the precipitate at first produced continues to redissolve, and then filtering the solution. According to Hardy metallic sodium does not act on pure dry chloroform, but if alcohol or wood spirit are present, marsh gas and hydrogen are given off.

Dr. Letheby thinks that much of the chloroform used in America is contaminated with alcohol ; for it has the low specific gravity of 1·45. This also may be one of the reasons for the unsatisfactory accounts which have come from that country of its bad and variable effects.

Aldehyde is recognised by its reducing action on the hydrated oxide of silver, and by its rendering *aqua potassæ* of a brown colour when heated with it.

Hydrochloric acid is a very common impurity in chloroform, and often exists in it to a very considerable extent. That containing this acid has often an irritating odour ; it reddens litmus paper, and affords, when shaken with a solution of nitrate of silver, a white precipitate.

Hypochlorous acid may be recognised by its odour, as also by its reddening, and then partially bleaching, a piece of litmus paper.

Chloroform from wood spirit is much less pure than that prepared from alcohol, but in both cases more or less of certain chlorinated oils are present, which can only be removed by agitation with, or by distillation from concentrated sulphuric acid. According to Gregory, impure chloroform may be recognised by the disagreeable odour which is left on a cloth moistened with it after it has evaporated, and by the yellow or brown colour it imparts to oil of vitriol when agitated with it. Pure chloroform placed upon oil of vitriol produces a contact surface convex downwards; impure chloroform gives a plane contact surface. Chloroform prepared from chloral is purer than even the best specimens made by the ordinary process; it is not affected by light, and when allowed to evaporate spontaneously, the last few drops have the same odour as the pure substance, instead of the unpleasant smell which can be distinctly observed with ordinary chloroform, even after purification with concentrated sulphuric acid.

The presence of these chlorinated compounds to any appreciable extent in chloroform, produces a marked effect upon the system. They occasion a peculiar throbbing headache, and a rapid prostration of the vital powers. These symptoms may often be observed when the chloroform is only inhaled for a short time; and there can be no doubt that they are very often the causes of the discomfort so often resulting from the use of certain samples of this anæsthetic.

The above-mentioned methods are more or less useful for ascertaining the actual purity of chloroform, *but none of them* indicate the proportion of the sophistication. The presence of alcohol is the most common, either from negligence in the rectification, or from after addition. M. Besnou has endeavoured to find an easy method of determining the quantity, by the use of the densimeter, and the areometer for acetometry.

He operated upon mixtures in various proportions, and compared their densities. These are appended under the form of a table which will enable the reader at once to follow the differences. It is from 100, as indicating perfect purity, to 75 of chloroform, or from 0 to 25 per cent. of alcohol in the liquid. In this table, *absolutely* pure anhydrous chloroform is not alluded to, but only the commercial product, and such as may be obtained by the ordinary operation of its manufacture:—

Real density.	Corresponding degree of the areometer.	Proportion of alcohol of specific gravity 1·35 mixed with it.	Ponderable quantity of alcohol per cent.
1·4945	47·60	—	0·00
1·4908	47·38	1	0·50
1·4874	47·16	2	1·00
1·4845	46·94	3	1·50
1·4772	46·47	5	2·50
1·4602	45·40	10	5·00
1·4262	43·00	20	10·00
1·4090	41·82	25	12·50

The diminution of the specific gravity by each per cent. of alcohol mixed with it at 4·°5 C., is consequently ·0034, whence it results, that chloroform mixed with ten per cent. of alcohol loses thirty-four degrees of the densimeter, and with twenty per cent. sixty-eight degrees; thus the density being determined by the areometer for specific gravity, to estimate the mixture it will only be necessary to divide the known difference by ·0034.

CHLORINE.—French, *chlore;* German, *chlor.*—This body was discovered by Scheele in 1774, and further investigated by Gay-Lussac, Thénard, and, above all, Davy, who established its elementary character and gave it the name it now bears, which is derived from χλωρος, yellowish-green, the colour the gas possesses.

It is obtained by heating aqueous hydrochloric acid with peroxide of manganese. The acid is a solution of hydrochloric acid gas—a compound of chlorine with hydrogen—in water. The peroxide of manganese is an oxygen compound of the metal manganese. The reaction which takes place in the operation is symbolically expressed by the following equation:—

$$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2.$$

The first result of the action is, indeed, tetrachloride of manganese, $MnCl_4$, thus:—

$$MnO_2 + 4HCl = MnCl_4 + 2H_2O,$$

but the tetrachloride, being a very unstable compound, soon breaks up into chloride of manganese and free chlorine, $MnCl_2$ and Cl_2, and thus the final result of the reaction is expressible through the first equation.

It may also be prepared by heating together common salt, manganese peroxide, and sulphuric acid—

$$MnO_2 + 2NaCl + 2H_2SO_4 = MnSO_4 + Na_2SO_4 + 2H_2O + Cl_2.$$

But the process represented by this reaction demands too high a temperature, and the best proportion for good practical results is expressed by the equation:—

$$MnO_2 + 2NaCl + 3H_2SO_4 = MnSO_4 + 2NaHSO_4 + 2H_2O + Cl_2.$$

In this country all chlorine is prepared from hydrochloric acid, which is obtained in enormous quantities in the course of the salt-cake manufacture.

Chlorine gas has, according to Bunsen, a specific gravity of 2·4482. A pressure of four atmospheres reduces it to a bright yellowish liquor of spec. grav. 1·33; the same liquid state is reached by exposing it to a temperature of 72° Fahr. It possesses a strong, suffocating odour. The readiest protection in an atmosphere charged with chlorine is to place a sponge saturated with spirit of wine over the mouth and nose; if the gas has already been inhaled to some extent, steam ought to be drawn into the lungs, or, according to Bolley, the vapours of aniline.

Chlorine combines with every other element except fluorine, and its affinity for some of the metals is very great; antimony, zinc, and several others, showered in powder into it, take fire and produce a brilliant combustion.

Metallic oxides heated in chlorine become chlorides; lime heated thus becomes chloride of calcium with liberation of oxygen.

A mixture of equal volumes of chlorine and hydrogen explodes, when exposed to sunlight, with violence, and the result of the union of the two elements is hydrochloric acid. The combination of the two gases can be effected without explosive violence by bringing the mixture under the influence of diffused daylight. Spongy platinum, or the electric spark, leads likewise to the union of the two elements.

Mixed with marsh gas (CH_4) chlorine burns with a pale green flame, forming hydrochloric acid, whilst the liberated carbon is deposited as soot.

Chlorine is soluble in cold water. With water cooled to near the freezing point it forms a crystalline compound of the composition $Cl\ (H_2O)_5$. Its solubility in water varies with the temperature, 1 volume of water absorbs—

VOLUMES OF GAS.

	According to PELOUZE.	According to GAY-LUSSAC.
At 32° Fahr.	1·75—1·80	1·43
“ 43½° “	—	2·08
“ 47° “	—	3·04
“ 50° “	2·75	3·00
“ 53½° “	2·55	—
“ 62½° “	—	2·37
“ 86° “	2·00—1·10	—
“ 95° “	—	1·61
“ 104° “	1·55—1·60	—
“ 122° “	1·15—1·20	1·19
“ 158° “	0·60—0·65	0·71
“ 212° “	—	0·15

The aqueous solution of chlorine decomposes readily when left exposed to the light; hydrochloric acid is formed with elimination of oxygen.

Formerly aqueous solution of chlorine was employed, especially in France, for bleaching purposes; at present it is entirely out of use.

Chlorine acts powerfully upon all vegetable and animal substances, and its action consists in combining with some (or sometimes the whole) of the hydrogen, which is a never absent constituent of all animal and vegetable tissues. Upon this property of chlorine rests its application in bleaching.

Chlorine forms four compounds with oxygen and hydrogen, which are ordinarily called acids, but which we prefer to consider, with Professor WILLIAMSON, as salts in which the place of the metal is occupied by hydrogen. The four compounds are :—

Hydric hypochlorite (usually, hypochlorous acid), $HClO$.—It is obtained by shaking up chlorine water with mercuric oxide, insoluble oxychloride of mercury and a dilute solution of hydric hypochlorite being formed; the latter can be somewhat concentrated by evaporation, but not without decomposition of the acid. The aqueous solution is colourless, and has a peculiar sickly odour. It is an exceedingly weak acid, being expelled by carbonic acid from its salts in presence of water. It has strong bleaching properties, and is present together with hydrochloric acid in the solution of chlorine in water. This can be shown by adding a solution of silver nitrate to the chlorine water, as long as any precipitate is formed, and filtering: the filtrate, from which the chlorine of the hydric chloride had been removed, shows all the bleaching power which the solution had before the addition of the silver salt.

On passing chlorine into a cold dilute solution of caustic potash, chloride of potassium and potassic hypochlorite are first formed—

$$2KOH + Cl_2 = KCl + KClO + H_2O.$$

On continuing the treatment with chlorine, the hypochlorite passes into the chlorate. This latter result is also arrived at by conducting chlorine gas into a hot or a concentrated solution of caustic potash.

A cold dilute solution of carbonate of potash leads, on being acted upon by chlorine, through two preliminary stages to the formation of potassic chloride and hypochlorous acid proper, Cl_2O, the so-called anhydrous acid.

Hydric chlorite (usually, chlorous acid), $HClO_2$.—It is formed by treating potassic chlorate, in the presence of hydric nitrate, with some reducing agent, as sugar, tartaric acid, &c. It is a greenish-yellow permanent gas of 2·65 sp. gr.; water dissolves ten times its own bulk of the gas. Heated to about 135° Fahr. it explodes.

Hydric chlorate (usually, chloric acid), $HClO_3$.—It is best prepared by adding dilute oil of vitriol to a solution of barytic chlorate, in quantity exactly sufficient to combine with all the barium, without leaving any sulphuric acid mixed with the hydric chlorate. Barytic sulphate is completely precipitated—

$$Ba(ClO_3)_2 + H_2SO_4 = BaSO_4 + 2HClO_3.$$

Its potassic salt forms, as already mentioned, when chlorine is passed into a hot concentrated solution of caustic potash—

$$6KOH + 6Cl = 5KCl + KClO_3 + 3H_2O.$$

Potassic chlorate is also formed by heating a solution of potassic hypochlorite—

$$3KClO = KClO_3 + 2KCl.$$

The aqueous solution of hydric chlorate may be concentrated by first evaporating at a temperature not exceeding 100° Fahr., and then completing the process by putting the partially concentrated acid into a vacuum over some strong oil of vitriol.

Hydric chlorate is a powerful oxidising agent: a piece of paper soaked with it takes fire in the air. Hydric chlorate itself is not explosive; but its salts, mixed with combustible bodies like charcoal, sugar, sulphur, &c., explode readily.

All its salts are readily soluble in water.

Hydric perchlorate (usually, perchloric acid), $HClO_4$.—It may be obtained by distilling at gentle heat potassic perchlorate with oil of vitriol; treating the distillate with argentic sulphate for the purpose of taking away free chlorine; decanting, adding barytic carbonate to fix the sulphuric acid, and again distilling with care. At first a very dilute acid comes over, but when the temperature has risen to 392° Fahr., a liquid of sp. gr. 1·65 passes—it is collected into a new receiver. This acid is a colourless liquid, which slightly fumes in the air. It may be still further concentrated by distilling it with four to five times its weight of sulphuric acid, when the greater part of it is decomposed into chlorine and oxygen, but a portion condenses in a mass of small crystals, and also in long four-sided prismatic needles, which settle in the neck of the retort. SERULLAS considers the two as different hydrates of hydric perchlorate.

A simpler mode of preparing it is to decompose the solution of potassic perchlorate by hydrofluosilicic acid: the potassium is carried down as fluosilicate, while hydric perchlorate remains in solution—

$$2KClO_4 + H_2SiFl_6 = K_2SiFl_6 + 2HClO_4.$$

The potassic perchlorate is obtained by fusing the chlorate, and continuing to heat it, until the evolution of oxygen has ceased; the remaining mass consists of potassic chloride and potassic perchlorate.

The perchlorate is the most powerful of the acids of chlorine; a dilute solution of it dissolves zinc and iron with evolution of hydrogen and formation of the perchlorates of these metals.

The bleaching properties of chlorine were first suggested by BERTHOLLET in a paper read to the French Academy in 1785. In 1787 Professor COPELAND and the Duke of GORDON commenced works in Aberdeen to make chlorine in large glass (WOOLF'S) apparatus, which was afterwards improved by the apparatus being made of hard wood. Bleaching by means of chlorine was introduced into Glasgow in 1789 by Mr. WATT, the well-known engineer, and from thence it soon found its way into Lancashire. As the demand for chlorine increased, the apparatus for its production was enlarged, and a vessel made of strong lead, fixed in a metal jacket, was substituted, a stone agitator being used to mix the charge of salt, manganese, and sulphuric acid.

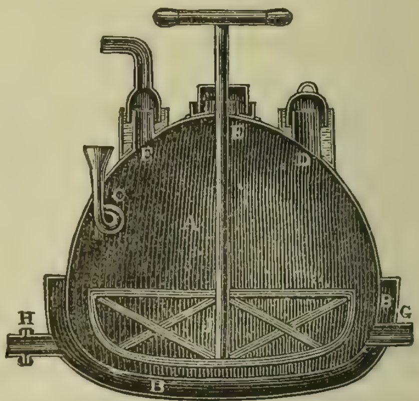
The first mode of using chlorine in bleaching was to transmit it through water till the latter was saturated; into this solution the goods were put, and heat was then applied to bring the chlorine to act upon the colouring matter. JAVELLE in 1790 suggested that a little caustic potash should be added to the water, and this plan was adopted in Liverpool, where a small work was commenced in 1792.

Great inconveniences attended this method of bleaching, and, as an improvement upon the system, the solution was diluted, and it was found to effect the decoloration equally as well as the strong liquor, without causing the many injuries which the latter occasioned. In consequence of the cloth becoming yellow after being bleached, recourse was had to alternate boiling in alkaline liquors, after the immersion in the bleaching medium; but the frequent exposure of the goods, as well as of the vessels containing the bleaching liquor, caused the liberation of too much chlorine, which proved a great impediment on account of its injurious effects upon the operatives, and hence the process could not be carried out. In the meantime, however, the fact was discovered that alkalies combine with more chlorine than water, retain it with more tenacity, and yield it more regularly to the colouring matter. The workmen now had more security; for the gas, being in chemical combination with the alkali, did not escape into the atmosphere, although this combination did not prevent it from operating upon the goods.

The next improved step in the application of chlorine was the use of lime instead of the alkalies; but the first methods of using it, namely, of steeping or passing the goods through lime water and then exposing them to the action of chlorine, were productive of some irregularities, which required a further improvement in the preparation. This improvement was accomplished by CHARLES TENNANT of Glasgow, who impregnated the lime water with chlorine, and took out a patent for his *bleaching liquor* in 1798. This was followed by one in 1799, according to which dry lime was employed for the absorption of the chlorine, and the product obtained, *bleaching powder*, has remained ever since the vehicle for the chlorine used in the bleaching industry. This last improvement is due to C. MACINTOSH, at that time partner in the firm, TENNANT & KNOX, Glasgow.

The vessels used in the older days for preparing chlorine on the large scale, were composed of strong sheet-lead, or partly of lead and partly of iron. Fig. 1 represents a section of one of these stills. A is the still: it consists of two parts, the lower one, B, being inclosed in a jacket of cast iron, steam is injected into the intermediate space for the purpose of heating the contents. Sometimes the lower half was constructed of cast iron, having a groove in the upper part, to which the top part was secured by a coat of good cement. In this case, heat was communicated by means of a slow fire placed under the cast-iron bottom. In the dome of the still there were four openings: into one, C, the solid materials employed were introduced, whilst the acid was added through the funnel opening, F. The gas evolved passed off by the pipe, E, to the purifier and chamber, where it combined with the lime, and the shaft of the agitator passed up through D.

Fig. 1.



Steam was introduced from an ordinary boiler through the pipe, H, and the materials, after the whole had been decomposed, were drawn off by the pipe, G. The four openings, C, D, E, F, were secured by water lutes, capable of bearing a pressure greater than that required in the chamber where the saturation took place.

When operations were carried on, the manganese and salt were introduced in the ratio of 100 parts of the former to 150 of the latter; about 185 of sulphuric acid, spec. grav. 1·6, were then added, and the covers luted on by pouring water into the several receptacles after the lids have been closed. The fire was then lighted, or the steam introduced, as the case may have been, till the temperature of the interior was raised to 180° Fahr., keeping the agitator worked from time to time to raise the manganese, which readily subsides on contact with the acid. In the proportions given above, the equivalents of the pure materials are taken, but commercial peroxide of manganese is never pure, 60 to 75 per cent. being its average value; hence it was necessary to proportion the salt and acid, in the ratio of the above numbers, to the percentage of pure peroxide. Where carbonate of soda or sulphuric acid was manufactured, the hydrochloric acid, which is obtained as a bye-product, was employed for generating chlorine.

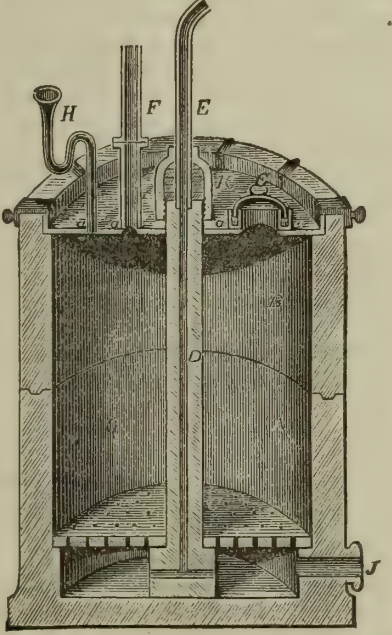
These lead alembics were used for a longer time in France than in this country. In the Mülhausen district they employed for some time large glass globes with long necks, heated upon a sand-bath, for the liberation of the chlorine from hydrochloric acid and manganese. But both forms suffice only for the production of comparatively small quantities of bleaching powder.

A vessel to manufacture chlorine on a large scale, and used, we believe, in Germany, is represented in Fig. 2. It is a cylinder of sandstone, the lower half of which, A, is carved out of a single block; the upper half, B, also of one piece, is joined to the lower by means of a grooved joint, which is filled up with a cement made of clay and boiled linseed oil. About 6 inches above the bottom the cylinder widens by 2 inches, and the rim thus formed bears a perforated bottom, C, upon which the manganese is deposited in large lumps. The tube, D, likewise of stone, passes below the perforated bottom, and is at its other end joined to the steam tube, E; the steam must, therefore, when introduced, enter the cylinder through the perforations of the false bottom. The top of the cylinder is closed by a lead cover, K, which is fastened down by means of iron clamps; this lid has an aperture, G, and the tubes, E, F, H, pass through it; tube E serves, as already stated, for the introduction of the steam; tube F is for the delivery of the chlorine; the bent tube, H, which ends in a funnel, for the introduction of the hydrochloric acid, and the opening, G, for throwing the lumps of manganese into the cylinder. The solution of manganese chloride, resulting from the action of the hydrochloric acid upon the manganese, is removed through J, which is kept closed by a wooden stopper whilst the reaction proceeds.

The decomposing vessels, called *stills*, used in England and Scotland are four-sided chambers. Such a still is usually about 5 to 6 feet square and 3 feet deep, and is constructed of large flags of stone about 6 inches thick. They are grooved and fixed together by a cement formed of tar and ground pipeclay, the sides being secured by strong iron bolts. Inside the still, about 18 inches from the bottom, there is placed a large flagstone, upon which the charge of manganese in small pieces is placed. The still is filled up with hydrochloric acid to within about 12 inches of the top, and this acid usually stands about 24° Twaddle's hydrometer. To facilitate the action a steam-pipe is introduced to near the bottom of the still, and sufficient steam forced in to keep the heat up at the end of the operation to about 150° Fahr.

The chlorine obtained is brought into contact with slaked lime, for the purpose of forming the bleaching compound. The selection and preparation of the lime requires much attention. The limestone for this purpose should be as free as possible from iron and manganese, because they impart to the bleaching powder a dark colour. The presence of considerable quantities of magnesia is said to be disadvantageous, inasmuch as the chloride of magnesium, which forms in the treatment with chlorine, absorbs water from the atmosphere with much more avidity than the corresponding lime compound, and the magnesium hypochlorite, which too is formed under the influence of the chlorine, decomposes very readily; two properties which easily lead to the spoiling of the bleaching compound. This statement is, however, contradicted by experienced manufacturers.

Fig. 2.



Two kinds of limestone are generally used, one called "clipp," which is brought from France, the other a pure limestone from Buxton.

The limestone having been calcined, and a lime tolerably free from the above defects having been obtained, the latter is slaked with water. The quantity of water used must be neither too much nor too little; in the former case, the hydrate of lime conglomerates into balls when treated with chlorine, and resists in that state penetration by the gas; in the second case, the absorption of chlorine falls very short from the numbers attainable by careful manipulation. The slaking is performed by watering the pieces of calcined lime, which are spread out in layers of not more than 6 inches in height, with a watering can, and turning them over as soon as they begin to swell and to emit steam. Pieces which appear unaffected after this treatment are immediately removed by the workmen.

When the slaking is finished, the lime hydrate is sieved, in order to separate small pebbles and other impurities. The sieved lime hydrate must then be left for a day or two, before being put into the bleaching powder chambers; it is asserted that lime fresh from slaking is not well adapted for absorbing chlorine. When properly prepared the fine lime should contain about 24 per cent. of water, not chemically united.

The chambers in which the lime is brought into contact with the chlorine are of stone or lead. In England the use of lead is almost general. The size of these chambers varies considerably; it depends entirely on the scale of the manufacturing establishment. They are usually about 60 feet long, by 30 feet wide, and 5 feet high.

The screened lime is spread upon the floor of the chamber in a layer of not more than 6 inches in height. Formerly it was laid on wooden trays, fixed in layers one above another; but experience showed that the former mode of distributing the lime is quite as effective with regard to a rapid absorption of the chlorine. When a rather thick layer of lime is saturated with chlorine, the superficial portion is always inferior in bleaching power to the lower portions.

Before admitting the chlorine into the chamber it is passed through a stoneware bottle, for the purpose of freeing it from water vapours, and also from particles of manganese chloride, which are carried over with the chlorine.

The supply of chlorine to the chambers must be so regulated as to prevent the heat, occasioned by the combination ensuing, from rising above 62° Fahr. But, according to Scheurer-Kestner, an elevation of the temperature to about 130° Fahr., consequent on the absorption of the chlorine, is not disadvantageous to the production of bleaching powder. Application of excess of chlorine, however, diminishes the proportions of available chlorine in the product, apparently in consequence of the formation of chlorite.

When the operation is complete the chambers are left closed, in order to allow the complete absorption of all the gas in them. The unabsorbed chlorine is generally drawn off into a fresh chamber of lime, which quickly absorbs it, or in some cases it is taken to the large chimney. The chamber door is then opened, and the bleaching powder is drawn towards it with wooden rakes; the casks are placed just inside the doorway, and are filled with bleaching powder (technically "packed") by a workman, who enters the chamber for the purpose, having previously tied a wet piece of thick flannel over mouth and nose.

Great care is to be observed in the packing of the powder. In the first instance, it is better to be cooled; exposure to the sun is to be avoided, for bleaching powder that has been, even for a very short time, under the influence of the sun's rays, is quite certain to decompose. The powder has to be packed firmly into the casks, and these must be free from moisture.

Any disregard of these precautions leads to a sudden explosive decomposition of the powder in the cask. The gas which on such occasions is met with has been recognised as oxygen; and the bulk of the bleaching powder is found to consist of chloride and chlorate of calcium.

The maximum amount of chlorine absorbed by 100 parts of hydrate of lime is, according to Graham, 41·3 parts, of which only 39 parts are available for bleaching, the remainder going to form calcium chloride and chlorate. The bleaching powder of commerce, however, averages from 35 to 37 per cent., but a product of a strength of 32 per cent. is considered to be more stable than a stronger one.

All bleaching powder is apt to lose gradually its available chlorine. J. Pattinson has made some experiments with the view of ascertaining the rate of this loss, and he finds that in the warmer season the average loss during a month may rise to 0·86 per cent., whilst in a winter month the loss is not more than 0·26 per cent.

The product of the chambers is, according to the most prevalent view at the present time, a mixture of calcic hypochlorite with calcic chloride, associated with which are free hydrate of lime and traces of calcic chlorate. The reaction between the hydrate of lime and the chlorine may therefore be represented thus—

$$2CaO + 4Cl = CaCl_2O_2 + CaCl_2.$$

The determination of the true nature of bleaching powder has been the object of numerous investigations since C. Mackintosh first prepared it. Originally bleaching powder seems to have been looked upon as simply a combination of chlorine with lime, and hence its name of *chloride of lime*. This view of the constitution of the bleaching agent was taken by Berthollet. But Berzelius, led by certain theoretical speculations, asserted that the chlorine existed in the compound as chlorous acid, and that bleaching powder was calcic chlorite. The subsequent discovery by Balard of hypochlorous acid (hydric hypochlorite) gave support to this view, although hypochlorous acid was substituted for the chlorous. Gay-Lussac, in adopting this theory, showed that bleaching powder gave, on being treated with a dilute mineral acid, hydric hypochlorite, which could be isolated by submitting the mixture to distillation by gentle heat.

This liberation of hydric hypochlorite from bleaching powder explains the action of the latter in the bleaching process. It was stated in the description of the operation of bleaching (See Bleaching) that on immersing the fabric in the solution of bleaching powder no bleaching effect, or at least none worth speaking of, shows itself; but the subsequent exposure of the cloth to the action of an acid leads to the desired decolorisation of the fibre. The chemical change which takes place in the treatment with acid is supposed to be the following:—

$$\begin{array}{ccccccc} \text{Calcic hypochlorite.} & & \text{Hydric sulphate.} & & \text{Calcic sulphate.} & & \text{Hydric hypochlorite.} \\ CaCl_2O_2 & + & H_2SO_4 & = & CaSo_4 & + & 2(HClO). \end{array}$$

But the decomposition does not stop here; the hydric hypochlorite breaks up into chlorine and oxygen; the latter oxidises the metal of the calcic chloride, and thus sets additional chlorine free—

$$CaCl_2 + CaCl_2O_2 + 2H_2SO_4 = 2CaSO_4 + 2H_2O + 2Cl_2.$$

But the view expressed above as to the true nature of bleaching powder is not the only one entertained by chemists. E. Millon viewed it as an oxychloride of calcium, $CaOCl_2$, analogous to calcium dioxide, which view was also taken by J. S. Muspratt.

A sample of bleaching powder analyzed by F. Rose, under the direction of Fresenius, yielded 26·72 per cent. of calcic hypochlorite, 25·51 calcium chloride, 23·05 calcic oxide, and 24·72 combined and hygroscopic water. On repeatedly triturating it with fresh quantities of water to a thin pulp, the calcium chloride was found to dissolve at the first trituration, the hypochlorite only at the third. Hence Fresenius concludes that the two salts exist in the bleaching powder merely in a state of mixture, or at most as a loose combination easily decomposed by water, and he views, therefore, bleaching powder as a mixture of hypochlorite and oxychloride of calcium, $CaCl_2O_2 + (CaCl_2.CaO)2H_2O$. The oxychloride is decomposed by water into chloride and hydrate of calcium.

J. Kolb found that the most concentrated preparation producible by saturating dry calcium hydrate with chlorine contains 38·5 per cent. bleaching chlorine, 45·8 lime, and 24·7 water, corresponding with the formula $Ca_3H_6O_6Cl_4$. In this product, the water and the whole of the lime are essential constituents, which cannot be removed without the breaking up of the compound. Commercial bleaching powder always contains a small excess of water, as well as free lime, which gives it a greater stability, an effect likewise produced by other inactive substances, such as carbonate or sulphate of lime. Kolb agrees with Fresenius as to the manner in which dry bleaching powder is decomposed by water.

The difference in the composition of dry bleaching powder and in that of its aqueous solution is best shown by their different behaviour to carbonic acid. The dry compound is entirely decomposed by carbonic acid, with evolution of chlorine, whereas from the aqueous solution even the greatest excess of carbonic acid precipitates only half the calcium as carbonate, and only with separation of hydric hypochlorite, which does not act upon the residual calcium chloride.

Professor Odling considers bleaching powder as a *compound*, not a *mixture*, of chloride and hypochlorite of calcium, chiefly on the ground that no calcium chloride can be extracted from bleaching powder by means of alcohol, and that bleaching powder is not deliquescent, like mixtures containing calcium chloride are.

Crace-Calvert draws, from experiments of his own, the conclusion that bleaching powder consists of 2 parts of chloride and 1 part of hypochlorite of calcium, a conclusion greatly at variance with the results obtained by other investigators.

Quite recently Goepner has returned to Millon's view of the constitution of bleaching powder, basing his opinion principally on the fact, observed by him, that in distilling a mixture of bleaching powder and sulphuric acid, no hydric hypochlorite but chlorine was obtained. But the experimental result noticed by Goepner is not borne out by the observation of other chemists, as has been pointed out, amongst others, by Schorlemmer.

Various other theories respecting the true constitution of bleaching powder have been brought forward, but we are compelled to be brief on purely speculative matters. We will only mention some of the more prominent writers on the subject—Kolb, Riche, Bobierre, Scheurer-Kestner, Richters and Juncker, Fricke and Reimer, and others.

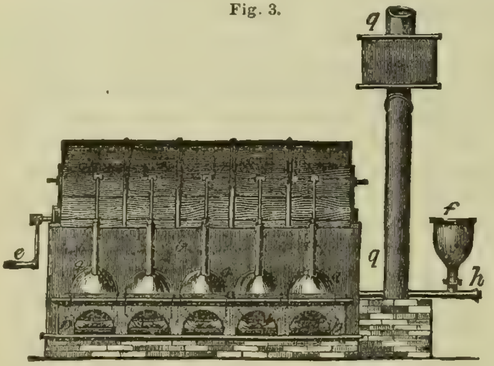
In many cases it is preferred to pass the chlorine into milk of lime, and thus to obtain a bleaching liquor instead of the solid powder. This is especially the case where the bleaching agent is to be used at the place of its production. Figs. 3 and 4 represent the side and the end view of the apparatus employed by the bleachers of Mulhouse for preparing this liquor. The glass balloons, *a a a*, are placed upon sand baths, which are fixed in brickwork and heated by furnace, *b b*, the flue of which circulates around each globe, and terminates in the pipe, *q q*. The manganese, salt, and sulphuric acid, or manganese and hydrochloric acid, are introduced into these vessels, and the gas as it is developed is discharged into the trough, *c*, by glass tubes. This trough is made of a kind of siliceous freestone, well annealed, and covered over with boards coated interiorly and cemented together with bituminous mastic. The cover is fixed into grooves in the walls of the concave part, and secured against chlorine escaping by cement, &c. In the interior of this vessel a horizontal cylinder, having a number of protruding arms with boards attached in the form of a helix, is placed; it is fastened air-tight, and turned by the winch, *e*. The milk of lime is introduced by the funnel, *f*, and the chloride of lime liquor drawn off at *h*.

H. Deacon has proposed to substitute carbonate of lime for the hydrate in the manufacture of bleaching liquor. Chalk or limestone is piled up in a tower, through which the chlorine ascends, whilst water trickles downwards. Or the chalk or limestone may be powdered, made into a milk, and then treated with chlorine in the ordinary apparatus.

We have seen that, in the production of chlorine by the action of manganese upon hydrochloric acid, chloride of manganese is formed, which, as such, has to be withdrawn from the circle of operations. The residual product, or "still-liquor," is, however, by no means a pure solution of manganese chloride, but contains, in addition to that compound, considerable quantities of ferric chloride and free hydrochloric acid. It was formerly thrown away and constituted a very serious source of river pollution. The nuisance resulting from this mode of disposing of it, together with the high price of manganese ores, have led to many attempts to utilize it, and it is now almost invariably treated for the regeneration from it of peroxide of manganese for use again in the manufacture of chlorine. Indeed, a large part of the chlorine made is produced by means of artificial peroxide of manganese regenerated from the residues of previous operations.

Dunlop, in 1855, was the first to suggest a practical method for recovering the spent manganese in a form capable of reapplication in the production of chlorine. His method consists in precipitating the manganese in the still liquor by means of calcium carbonate, and decomposing the resulting manganese carbonate by heat. The plan, as still carried on in the factory at St. Rollox near Glasgow, is the following:—The still-liquor is treated with either powdered chalk or milk of lime, to neutralize the free acid and decompose the ferric chloride contained in it, and is then allowed to stand until all insoluble matters have subsided. The clear solution of manganese chloride is then intimately mixed with milk of chalk, and the resulting milky liquid is run into large iron boilers, through each of which passes horizontally an iron shaft, furnished with a number of projecting arms. This shaft having been put into revolution, so as to keep the contents of the boilers agitated, steam is admitted into them under a pressure of from 2 to 4 atmospheres, and by the combined action of heat and pressure the decomposition of the manganese chloride by the calcium carbonate is finished in about four hours. The manganese carbonate is then allowed to subside, the calcium chloride solution is run off, the precipitate carefully washed, and thrown up in heaps on an inclined surface to drain.

Fig. 3.



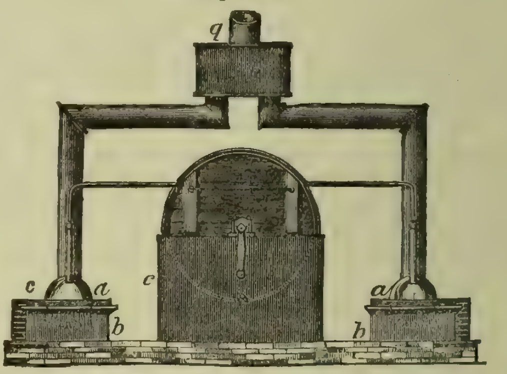
The partially dried material is placed in small low waggons of sheet iron, supported on rollers, and slowly drawn through an oven by means of a chain. The oven holds forty-eight of these little waggons. It is 50 feet long, 12 feet wide, and 10 feet high. A fire-brick flue runs down the centre of the bottom of the furnace, and is connected at the far end with two return metal pipes, which lie on each side of the flue. A uniform heat of about 660° Fahr. is maintained in the oven, in which four lines of rails are laid for the small waggons to traverse.

The half-dried material loses all its water and part of its carbonic acid as the waggons pass along the first line of rails, and as they return down the second line, a further escape of carbonic acid ensues, and ultimately the expulsion of all the acid, and the peroxidation of the manganese is completed on the third and fourth lines. This operation lasts about forty-eight hours, and the colour of the material gradually changes from white to brown, and then to black. The ends of the oven are closed by loose hanging doors, so that a sufficient supply of air is always insured. The fire-place is situated below the floor of the oven, and requires the greatest attention.

The product resulting is a mixture of oxides of manganese, containing about 72 per cent. of manganese peroxide.

Clemm sought to improve this method by substituting magnesium carbonate for the chalk with a view to the recovery of the chlorine, which in Dunlop's process is lost in the calcium chloride, since the magnesium chloride yields hydrochloric acid on treatment with steam at a high temperature.

Fig. 4.



This modification, however, has been found impracticable, and even the original form of Dunlop's process has not proved advantageous enough to lead to its adoption by more than a single firm of manufacturers. Messrs. Tennant still employ it at St. Rollox, but in their new works at Newcastle-on-Tyne recover by H. Weldon's process, described below.

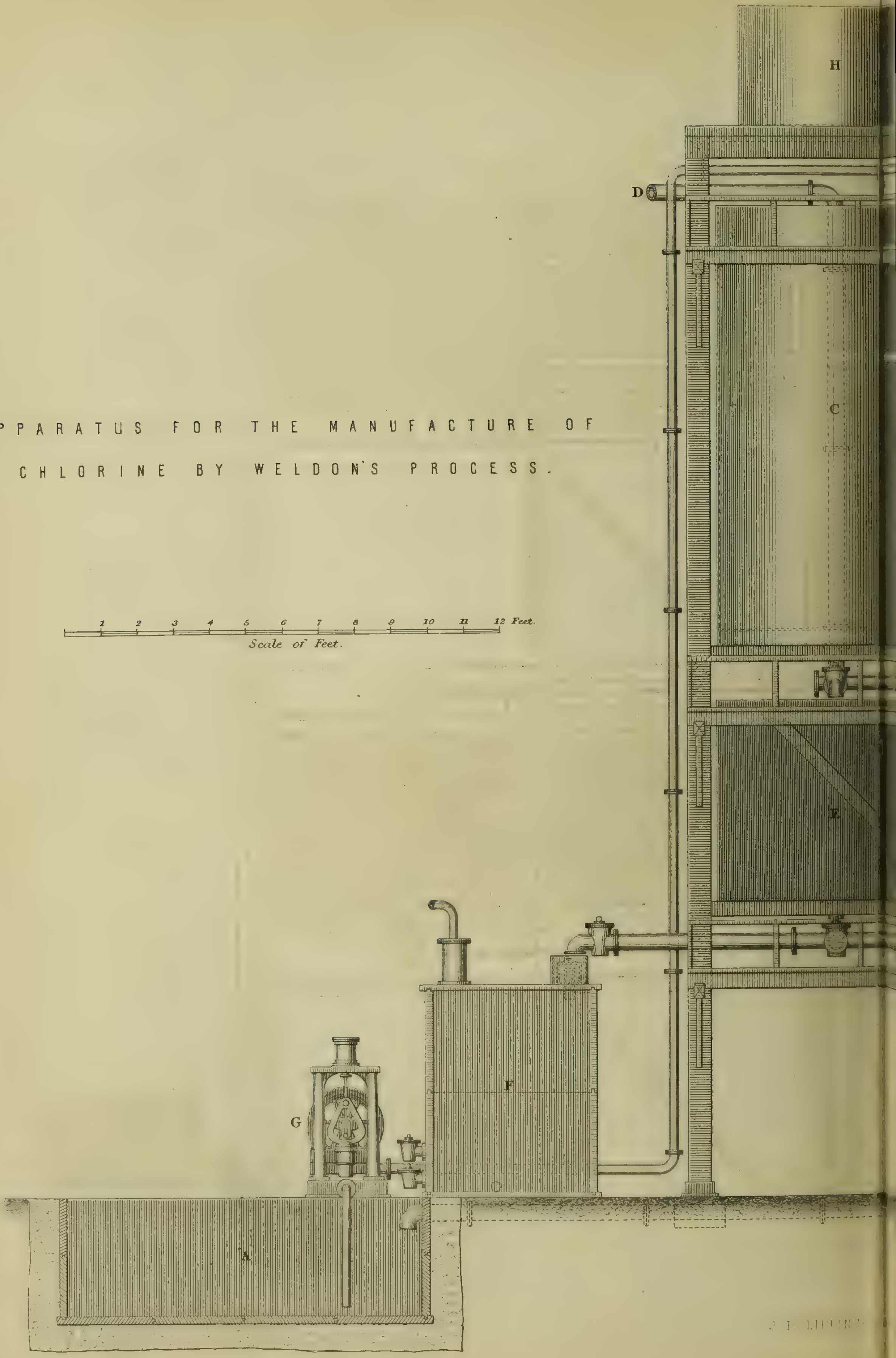
P. W. Hofmann attempted the regeneration of the manganese by means of the mixture of calcic polysulphides obtained by lixiviating blackash residues that had been exposed to the influence of the atmosphere. The sulphide of manganese produced was burnt, whereby sulphurous acid and manganese oxide were formed; the latter was heated with sodium nitrate, and thus transformed into a substance containing 55 per cent. of peroxide. The oxides of nitrogen which originated in the last operation were sent into the vitriol chambers.

F. Kuhlmann, of Lille, some time ago proposed

CHLO

APPARATUS FOR THE MANUFACTURE OF CHLORINE BY WELDON'S PROCESS.

Scale of Feet.



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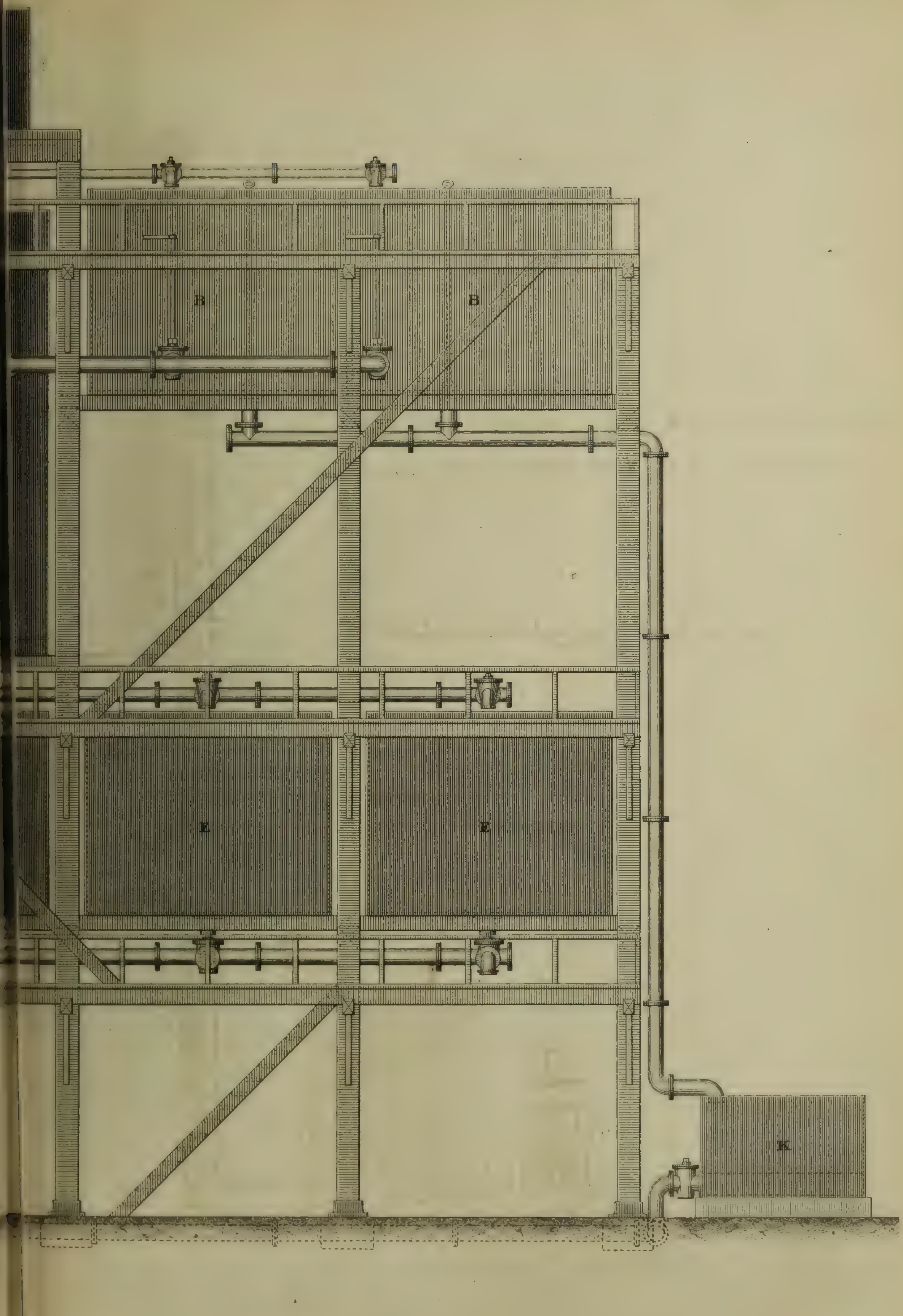
RINE.   *PLATE I.*



PHILADELPHIA

to revive the spent manganese by means of hyponitric acid. He finds that manganese nitrate heated to 390° Fahr. furnishes pure manganese peroxide. If the escaping gases, hyponitric acid, and other oxides of nitrogen, are mixed with air and passed over hydrated oxide of manganese, the latter is transformed into nitrate. The hydrated oxide of manganese is obtained from the still liquor by precipitation with lime. Kuhlmann says that he can recover in this manner 88 per cent. of the manganese originally employed in the decomposition of hydrochloric acid.

Kuhlmann's process is, moreover, only a modification of the method described by Schlœsing in 1863. This method consists in heating a mixture of nitric acid and hydrochloric acid with manganese peroxide; thus are formed chlorine, manganic nitrate, and water. The nitrate breaks up on heating, as above stated, into hyponitric acid and manganese peroxide; the hyponitric acid oxidises again to hydric nitrate. The successive stages of the reaction may be expressed thus:—

(1.) $2HCl + 2HNO_3 + MnO_2 = Cl_2 + Mn(NO_3)_2 + 2H_2O$.
(2.) $Mn(NO_3)_2 = MnO_2 + N_2O_4$.
(3.) $N_2O_4 + H_2O + O = 2HNO_3$.

But the regenerative process, which has hitherto been found most practical, is the one proposed by Walter Weldon. It rests on the fact that recently precipitated protoxide of manganese suspended in solution of chloride of calcium is, in the presence of excess of lime, easily oxidized to peroxide by means of air injected into the liquor. It is the employment of an *excess* of lime which makes Weldon's method really available for practical purposes. The possibility of oxidizing the precipitate obtained by adding simply an equivalent of lime to the residual liquors was previously known, but all attempts to turn it to practical account had failed. Weldon discovered that whereas, when manganese protoxide by itself is treated in the wet way with air, one-half is the maximum proportion of it which can thereby be converted into peroxide, the association of a certain proportion of lime with the protoxide so treated will enable the whole of it to become converted into manganese peroxide, and this in less than one-twentieth of the time required for the peroxidation of half of it when lime is not present. It is to these facts that the brilliant success of Weldon's method is chiefly due.

The process, as carried out on the manufacturing scale, is as follows:—The residual liquors from the still, F (see Plate I., Chlorine), in which the reaction between hydrochloric acid and manganese took place, are run into a well, A, termed the *neutralizing well.* Here the free hydrochloric acid of the still liquor is neutralized, and its ferric and aluminic chloride decomposed, by treatment with limestone or chalk, the action of which is accelerated by energetic agitation. After this treatment the now neutral liquor consists of a mixed solution of chloride of manganese and chloride of calcium, holding in suspension small quantities of iron oxide and alumina, some little excess of chalk, and not an inconsiderable quantity of lime sulphate. The last compound owes its origin to the sulphuric acid, which is present in all hydrochloric acid produced in alkali works.

From the neutralizing well, which is usually 6 feet deep by 20 feet diameter, the liquor is pumped up, by means of the pump, G, into the tanks, B B, placed about 40 feet above ground, and called the *chloride of manganese settlers.* In these settlers the solid matters suspended in the liquor subside within from two to four hours, leaving the bulk of the faintly rose-coloured liquor bright and clear.

The clarified solution of manganese and calcium chlorides is then drawn off by means of syphons, which can be lowered or raised in the settlers to any desired level, and run into the vessel, C, called the *oxidizer.* This is usually an iron cylinder of from 8 to 12 feet in diameter, and 20 to 35 feet in depth. Two pipes go down nearly to the bottom of the oxidizer, a large one, D, for conveying a blast of air from a blowing engine, and a smaller one for the injection of steam; the steam is intended to raise the contents of the oxidizer to 130° to 140° Fahr.; but this is often unnecessary, since the liquor reaches the oxidizer in a sufficiently hot state. Immediately above the oxidizer, C, is a reservoir, H, for the reception of milk of lime. This latter has to be carefully prepared, since on its degree of fineness depends the readiness of its action in the oxidizer. It is kept continuously agitated to secure a uniform consistency, and should contain 15 to 20 lbs. of hydrate of lime in every cubic foot of cream.

The oxidizer having received a charge of clear liquor from the chloride of manganese settlers, and this liquor having been heated by steam to the proper degree, if it did not reach the oxidizer sufficiently hot, the blowing is begun, and simultaneously milk of lime is run into the oxidizer as rapidly as possible, until the filtrate from a sample ceases to give a manganese reaction with solution of bleaching powder. A further quantity of milk of lime is next added, the contents of the oxidizer then forming a thin white mud, consisting of a solution of calcic chloride holding in suspension a mixture of protoxide of manganese and free lime. The injection of air being continued, this thin white mud rapidly darkens in colour, and at length what was a thin white mud has become a thin black mud, consisting of solution of chloride of calcium holding in suspension certain compounds of MnO_2, partly with MnO, but mainly with lime, to which Weldon has given the name of "manganites."

The quantity of lime which has to be put into the oxidizer before the filtrate from a sample of its contents ceases to give a manganese reaction, varies very considerably. Recently precipitated protoxide of manganese dissolves very appreciably in neutral solution of chloride of calcium, its solution therein comporting itself with reagents exactly like solutions of manganese salts. It dissolves also in solution of oxychloride of calcium, that is to say, in solution of chloride of calcium containing dissolved lime; its solution in oxychloride of calcium *not* giving the ordinary manganese reactions. Hence, even if all portions of the lime added to the chloride of manganese in the oxidizer were capable of acting on chloride of manganese equally readily, manganese could not cease to be so in solution as to be detectible by ordinary reagents until more than an equivalent of lime had been added — until enough had been added, that is to say, not only to decompose all the chloride of manganese, but also to form a certain quantity of oxychloride of calcium. It is never the case, however, that all portions of the lime used are capable of acting on the chloride of manganese with equal readiness. The lime used always contains a larger or smaller proportion of particles coarser than the rest, which coarser portions cannot of course act so rapidly as the finer portions, and as the decomposition of the chloride of manganese requires to be completed as quickly as possible, those portions of the lime which will not act upon it instantly are scarcely allowed time to act upon it at all. These coarser portions of the lime thus contribute very little to the decomposition of the chloride of manganese, though they afterwards dissolve completely in the hot solution of chloride of calcium, and then play their full part in the reactions which take place during the subsequent blowing. The proportion of the lime which thus does not act on the chloride of manganese varies with the source of the lime, and with the manner in which it is prepared; so that the quantity of lime which has to be added to a charge of chloride of manganese liquor in the oxidizer before the filtrate from a sample of the resulting mixture ceases to become coloured on addition of solution of bleaching powder, varies from about 1·1 to 1·45 equivalents. The further quantity of lime which is added after that point has been reached is now usually so much as to raise the total quantity to about 1·5 or 1·6 equivalents, being from one-half to six-tenths in excess of the quantity which actually takes part in the decomposition of the chloride of manganese.

It has already been stated that if only so much lime is employed as is necessary to precipitate the manganese from its solution, not more than half the precipitated protoxide of manganese can be peroxidized, and this only very slowly. To insure a greater and more rapid yield of peroxide, a larger portion of lime is required. But we have now to notice that too large a proportion of lime produces compounds which resist peroxidation. If this occurs, a fresh quantity of chloride of manganese has to be added in order to destroy those compounds. Indeed, in some works, the addition of a little chloride of manganese solution, after samples from the oxidizer cease to show an advance in oxidation, is made now in all cases.

The reason of this addition of "final liquor," as it is called, is as follows:—The compounds formed in the oxidizer are chiefly two; one consisting of an equivalent of MnO_2 combined with an equivalent of MnO, and the other of an equivalent of MnO_2 combined with an equivalent of CaO. About 20 per cent. of the MnO_2 is usually combined with MnO, and about 80 per cent. of it with CaO. The MnO and CaO thus combined with the MnO_2, are classed together under the name of "bases," for which every batch of mud is always carefully tested. Seeing that the bases neutralize hydrochloric acid without liberating any chlorine from it, the smaller their proportion to the MnO_2 of course the better. Now there are two compounds of MnO_2 with CaO, the one containing an equivalent of each constituent, and the other containing two equivalents of MnO_2 per one equivalent of CaO. Per equivalent of chlorine liberated, the former consumes three equivalents of hydrochloric acid, but the latter only two and a half. Under some circumstances, which need not here be entered into, the latter compound is formed directly; but when the operation in the oxidizer is so performed as to produce chiefly the compound containing a full equivalent of CaO per equivalent of MnO_2 in it, "final liquor" is employed, because one half of the lime in that compound is held more loosely than the other half, and can decompose chloride of manganese. The effect of final liquor, under the circumstances in question, is thus to reduce the proportion of bases to MnO_2, by converting the compound of one of MnO_2 with one of CaO into the compound of two of MnO_2 with one of CaO, and at the same time giving a further quantity of MnO, which a slight continuation of the blowing, more or less, completely peroxidizes.

The blowing lasts usually from two to four hours. The quantity of air which requires to be blown into the oxidizer, per given quantity of peroxide of manganese made, varies with a considerable number of conditions, but more especially with the depth of the charge operated upon, and with the quantity of manganese contained in a given volume of it. Within all practicable limits, increase of the depth of the column blown into is equivalent to increase of the quantity of air blown; and the more particles of protoxide are contained in a given volume of the charge, the larger is the total surface which they present for the air to act upon, and the greater is the proportion of the total oxygen injected which becomes absorbed. The proportion of the oxygen absorbed to the quantity blown in is of course greatest at the commencement of the operation, and afterwards continually diminishes, a time at length arriving, if the blowing be continued long enough, at which no more oxygen is absorbed at all; the proportion of the total quantity of oxygen absorbed to the total quantity blown in is also considerably influenced by how nearly to that point the operation be continued.

The following figures show the progress of peroxidation every half hour at two factories, one in France and one in Lancashire:—

At a Factory in France.

The charge consisted of 18,000 litres of chloride of manganese liquor; steam having been injected until the temperature had reached 60° C., and milk of lime equal to 1·6 equivalents of the chloride of manganese having been added, the blowing began at 2.50 P.M. Every half hour a sample was taken and tested for peroxide of manganese.

CHLORINE.

WELDON'S CHLORINE STILL.

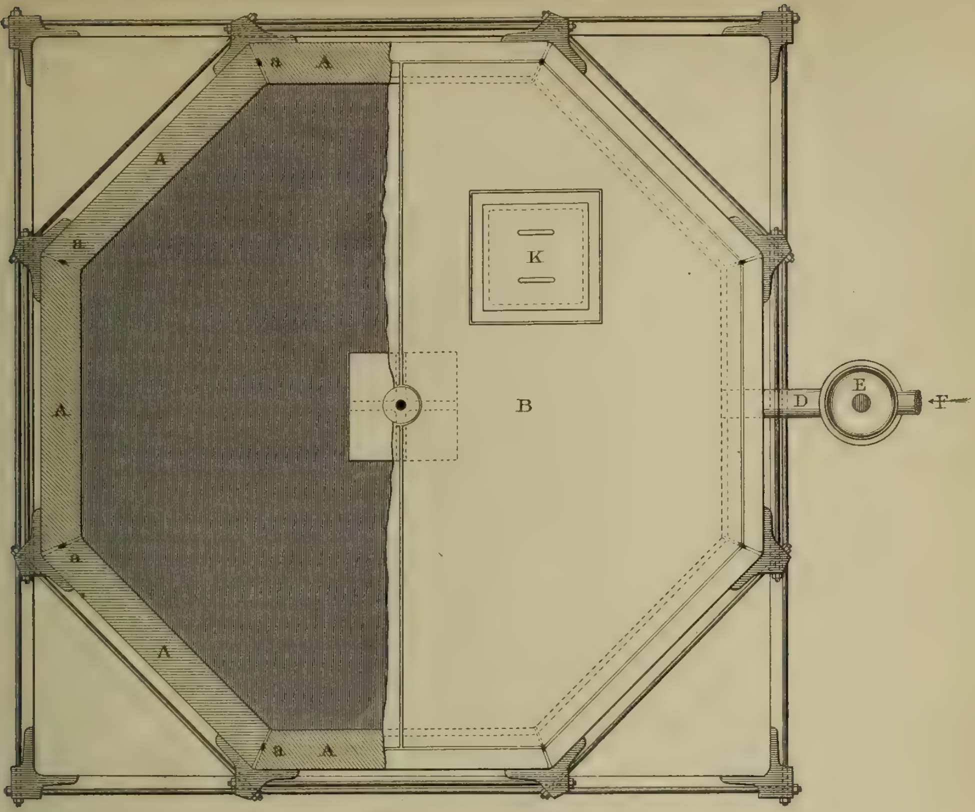


Fig. 1.

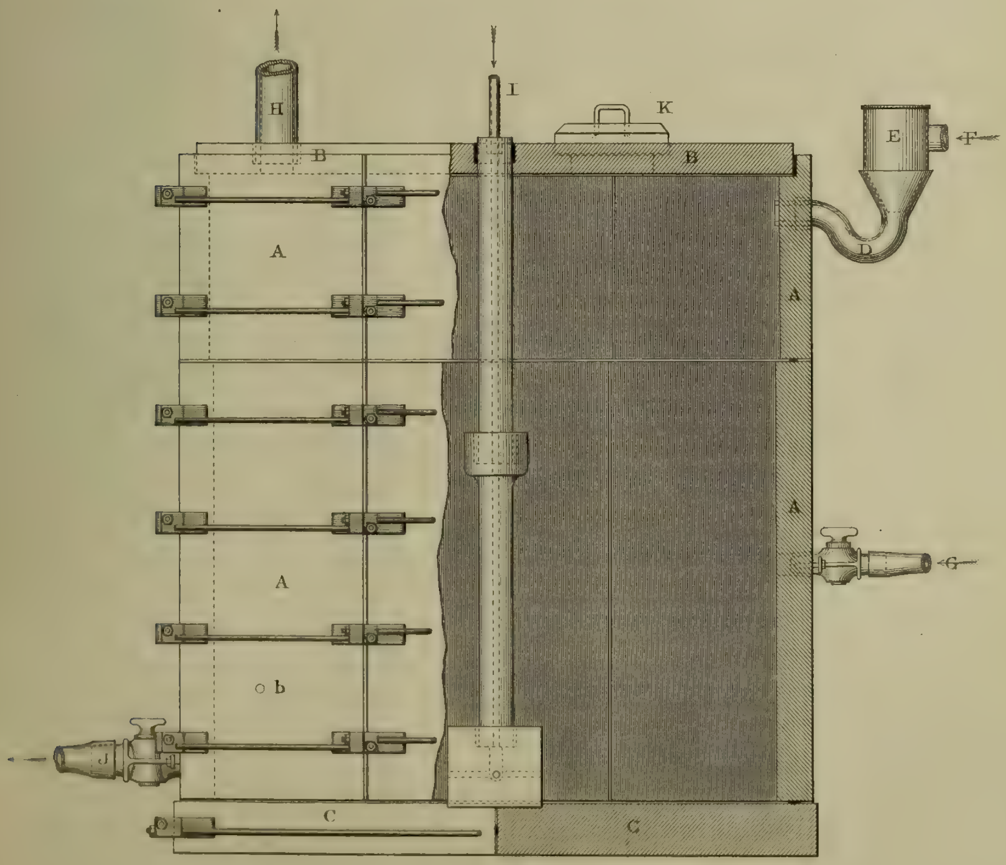


Fig. 2.

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At 2.50 P.M. there were in the oxidizer 0·00 grms. of peroxide of manganese per litre.

At 3.20 P.M. there were in the oxidizer 10·1 grms. of peroxide of manganese per litre.

At 3.50 P.M. there were in the oxidizer 18·6 grms. of peroxide of manganese per litre.

At 4.20 P.M. there were in the oxidizer 28·9 grms. of peroxide of manganese per litre.

At 4.50 P.M. there were in the oxidizer 36·3 grms. of peroxide of manganese per litre.

At 5.10 P.M. there were in the oxidizer 40·9 grms. of peroxide of manganese per litre.

At this stage the batch was run off. The whole quantity of mud measured 51,900 litres, and contained, therefore, 51,900 × 40·9 grammes = 2122 kilogrammes of manganese peroxide, which was combined with 0·66 equivalent of bases per equivalent of peroxide.

At a Factory at St. Helens.

The charge consisted of 1243 cubic feet of chloride of manganese liquor. After it had been heated to 130° Fahr., and mixed with 1·6 equivalent of lime, the blowing began at 12.15 P.M.

A 12.15 P.M. there were in the oxidizer 0·00 lbs. of peroxide of manganese in a cubic foot of the mud.

At 1.30 P.M. there were in the oxidizer 0·83 lbs. of peroxide of manganese in a cubic foot of the mud.

At 2 P.M. there were in the oxidizer 1·12 lbs. of peroxide of manganese in a cubic foot of the mud.

At 2.30 P.M. there were in the oxidizer 1·35 lbs. of peroxide of manganese in a cubic foot of the mud.

At 3 P.M. there were in the oxidizer 1·64 lbs. of peroxide of manganese in a cubic foot of the mud.

At 3.30 P.M. there were in the oxidizer 1·97 lbs. of peroxide of manganese in a cubic foot of the mud.

At 4 P.M. there were in the oxidizer 2·24 lbs. of peroxide of manganese in a cubic foot of the mud.

At 4.30 P.M. there were in the oxidizer 2·36 lbs. of peroxide of manganese in a cubic foot of the mud.

At 4.45 there were added 124 cubic feet of chloride of manganese liquor, and blowing was continued till 5.15, when the liquor of the oxidizer contained 2·37 lbs. of peroxide per cubic foot. The batch was then run off. It measured 1751 cubic feet, containing 1751 × 2·37 = 4149 lbs. of peroxide of manganese, which was combined with 0·72 equivalent of bases.

The mechanical power expended in the injection of the air into the oxidizer averages between 4 and 5 horse-power for one hour per 100 lbs. of manganese peroxide made. The quantity of chlorine contained in a ton of bleaching powder at 37 per cent. should only require 1020 lbs. of peroxide; but, owing to the various losses of chlorine which occur in the manufacture of bleaching powder, the quantity of manganite mud actually used per ton of bleaching powder made by means of it, is ordinarily the quantity containing about 1100 lbs. of peroxide. The production of the proportionate quantity of mud may be said to require the expenditure of 40 to 45 horse-power for one hour.

The contents of the oxidizer, consisting of a solution of chloride of calcium, in which the peroxide of manganese combined with manganese protoxide and lime is suspended, are now run off from C (Plate I.), into one of a range of settling tanks, E E, called the *mud settlers*, which are placed below the level of the oxidizer. There the mud is left at rest until it has settled as far as it will, usually until about one half of its volume has become clear. This requires about three or four hours. The clear part is then decanted by means of a swivel pipe. It is a perfectly pure solution of chloride of calcium, and is usually thrown away. The admission of this waste liquor into the rivers has, according to the opinion of the Rivers' Pollution Commission, no other ill effect than that of rendering the water a little harder.

The mud from the mud settlers, containing from 4 to 5 lbs. of manganese peroxide per cubic foot, is then ready for use in the decomposing still, F, where it is made to react upon hydrochloric acid. The still is constructed of slabs of hard siliceous sandstone, and is usually in the shape of an octagonal prism. Figs. 1 and 2, Plate II., represent respectively a section (in part), and an elevation (in part). A A, &c., are the slabs of sandstone. Each side of the still is formed of two slabs; the lower, about 7 feet high and 7 inches thick, and the upper, about 3 feet high and 6 inches thick; the width of each slab is about 4 feet. The slabs are held together by iron rods and screws (as seen in the diagrams), and where they join one another a rope of india-rubber, *a*, is inserted. The top, which consists of two stones, B B, is caulked down into a groove with red lead and oakum. The bottom, C C, which must rest on a good foundation, and which may be in two stones (as shown in the diagram), or even in four, has a thickness of 10 inches. D is an earthenware pipe widening into a funnel; into this fits a lead tube, E, from which a smaller tube, F, leading to the mud settlers, branches off. G is an earthenware tap for the admittance of the hydrochloric acid; H, the chlorine delivering tube; I, a pipe for the injection of steam, either of stone or of earthenware; J is a tap, of stoneware like G, for the elimination of the spent still liquor, which is then conveyed to the neutralizing well; and K is a manhole for admitting a workman when the still requires cleaning or repairing; at *b* is a small cock for drawing samples during the progress of the operation.

The operation in the still commences by its being charged with hydrochloric acid. (This is the reverse of the method formerly employed with native manganese, the native manganese being put into the still first, through a manhole, the still then closed, and the acid run in by a cock.) The still having been charged with acid, settled mud is run in upon the acid in a gentle stream, which can be regulated at will by a cock. Steam being gently injected at the same time, the mud dissolves almost immediately on reaching the acid, and chlorine comes off in an even current, the force and flow of which can be regulated with the utmost nicety by regulating the admission of the mud. When all the acid has been decomposed and neutralized except to the extent of from 6 to 8 ounces HCl per cubic foot, which at some works is at the end of two hours, and at others at the end of from four to six hours, the contents of the still are run off into the well placed below it, and there the round of operations above described is recommenced. The process is thus a continuous one, and theoretically enables the initial quantity of manganese to serve over and over again an indefinite number of times.

In practice there is, however, always a loss of a small percentage of manganese It has above been stated that the chloride of manganese liquor, after neutralisation with chalk, is left for a while at rest, before being run into the oxidizer, in order to allow sulphate of lime and other solid substances to subside. This deposit has, before being finally removed, to be washed carefully, in order to avoid throwing away with it the greater part of the manganese chloride, which it retains mechanically. This is done in tank K. Now, this deposit constitutes the only unavoidable source of loss of manganese; for though an exhaustive washing could easily be effected, the wash waters would, on account of their bulk, be of little use. A loss from about 2 to 4 per cent. (some chemical manufacturers say 8 to 10), must therefore be suffered with its removal. It is, indeed, possible to reduce this loss by careful working to less than 1 per cent., but such delicate working is only rarely attainable in extensive manufacturing operations.

Other possible sources of loss are leakage of vessels, and the running away of mud by careless workmen with the chloride of calcium solution from the mud settlers. The former of these two sources of loss ought never to exist, and the latter can be eliminated by passing the chloride of calcium solution before it is thrown away into catch-pools, in which any mud that may have come with it may be deposited.

With regard to the chief source of loss, the removal of manganese chloride with the lime sulphate, WELDON has proposed to do away with it by trying to obtain for the still operation hydrochloric acid free, at least from any appreciable quantities, of sulphuric acid. He believes this could be done by conducting the condensation of the hydrochloric acid gas coming from the salt-cake furnaces in such manner that the sulphuric acid should be retained in a special vessel intermediate between the furnaces and the present condensing apparatus. Should this plan succeed, the free hydrochloric acid of the still liquors could be neutralized by manganese mud, instead of by chalk, and this neutralization could be carried out in the still itself; dispensing with the present neutralizing wells, avoiding the chief source of loss of manganese, and utilizing that portion of the acid employed, which now leaves the stills in the free state, and is neutralized in the wells by chalk.

The chlorine produced by means of the artificial peroxide of manganese is declared to be perfectly pure, and yields a strong bleaching powder. Moreover, from 20 to 25 per cent. more bleaching powder may be produced from a given quantity of acid by means of WELDON'S artificial manganese, than by means of native manganese. This larger yield of chlorine is mainly due to the artificial manganese being so easily soluble that it can very readily be caused to neutralize from 95 to 99 per cent. of the hydrochloric acid employed, which is a much larger proportion than can be arrived at with manganese ores. Further, the yield of bleaching powder is not only of high strength, but it is so with great regularity. The following table shows the average strength, for thirteen consecutive weeks, of the bleaching powder made by six large manufactories:—

Week.	Factory.					
	I.	II.	III.	IV.	V.	VI.
1st	36·9	37·8	36·7	36·3	36·6	36·6
2nd	36·1	36·8	36·7	36·2	35·1	37·4
3rd	36·5	38·0	36·6	36·1	37·2	37·9
4th	35·9	37·1	35·9	36·2	36·8	37·1
5th	35·8	36·9	36·0	36·3	36·5	37·8
6th	36·0	37·0	36·2	35·9	36·5	37·2
7th	36·5	36·0	36·3	36·6	35·8	36·8
8th	36·3	36·8	36·3	36·3	35·0	37·1
9th	36·4	36·3	36·8	35·7	35·2	37·0
10th	36·5	36·7	36·3	36·0	36·2	37·6
11th	36·8	36·8	36·2	35·9	36·0	37·2
12th	36·8	35·9	35·6	35·6	36·1	37·2
13th	36·7	35·2	35·9	36·1	36·9	37·5

When we finally consider the costs of production between the old and new processes, it may safely be said that a decided advantage has been obtained by the latter; but the price of manganese, limestone, and coals varies so much from year to year that it is difficult to state it exactly in figures—for instance, in 1873 the price of manganese was £7 10*s.* per ton, and in 1875 it was only £5 5*s.* per ton: and so far as we can ascertain on good authority, the price is tending steadily downwards.

WELDON'S process, as above described, yields in an available form about one-third of the total chlorine contained in the acid employed, two-thirds going away as chloride of calcium. Finding, very shortly after the introduction of this process, that it was threatened with competition by the very beautiful process of H. DEACON, which will be described below, and which was at that time believed to be capable of yielding a larger proportion of chlorine, per unit of acid employed, than can be obtained by means of artificial peroxide of manganese regenerated by means of lime, WELDON devised, and essayed on a considerable scale, a process by which magnesia was used instead of lime for the regeneration of the manganese, and which was capable, theoretically, of yielding in the free state the whole of the chlorine contained in the acid employed (see page 486).

The methods of testing employed in connection with WELDON'S process are as follows:—

I. *For* MnO_2.—The quantity of mud usually employed is 1 cubic inch. It is added to a solution of a known quantity of protosulphate of iron in hydrochloric acid. The quantity of protosulphate used must be in excess of the quantity which the MnO_2 in the cubic inch of mud can oxidize: 70 grains of the crystallized protosulphate will usually give a sufficient excess per cubic inch of the mud as run from the oxidizer, or 150 grains per cubic inch of settled mud in the state in which it goes into the stills. If the iron salt be in excess, the mud will dissolve instantly in the cold to a clear yellow solution; if the solution be brown, enough iron salt has not been used, and the determination should be recommenced upon a fresh cubic inch of mud, using a larger quantity of protosulphate. The amount of the protosulphate left unoxidized must then be determined by addition of a standard solution of bichromate of potash, until a drop of the liquid, added to a drop of solution of ferricyanide of potassium on a white porcelain slab, ceases to give a blue colour.

It is most convenient for the bichromate solution to be of such strength that one measure of it is equal to either one grain or half a grain of $FeSO_4.10H_2O$.

The number of grains of protosulphate of iron oxidized by the MnO_2 in one cubic inch of mud, divided by 25·88, gives the pounds of MnO_2 in a cubic foot of the mud.

II. *For Bases.*—A cubic inch of the mud is added to a solution of a known quantity of oxalic acid. The quantity of oxalic used should not be less than at the rate of 75 grains of the crystallized acid per 100 grains of protosulphate oxidized by a cubic inch of the same mud. When the effervescence produced by the addition of the mud to the oxalic acid has ceased, or nearly so, the resulting mixture is gently heated, but not quite to the boiling point. If enough oxalic has been used it is then perfectly white. If it is not perfectly white, the determination must be recommenced, using more oxalic acid. The excess of oxalic acid is then determined by a standard solution of soda or potash. The proportion of bases to MnO_2 in the mud is then found by the appended table, as follows:—As the number of grains of crystallized protosulphate of iron oxidized by a given volume of the mud is to the number of grains of crystallized oxalic acid decomposed and neutralized by the same volume of the mud. so is 100 to a figure in column A of the Table against which in column B is the proportion of bases per equivalent of MnO_2 in the mud.

TABLE FOR PROPORTION OF BASES.

A	B	A	B	A	B
69·5	1·066	65·00	·868	60·50	·670
69·25	1·055	64·75	·857	60·25	·659
69·00	1·044	64·50	·846	60·00	·648
68·75	1·033	64·25	835	59·75	·637
68·50	1·022	64·00	·824	59·50	·626
68·25	1·011	63·75	·813	59·25	·615
68·00	1·000	63·50	·802	59·00	·604
67·75	·989	63·25	·791	58·75	·593
67 50	·978	63·00	·780	58·50	·582
67·25	·967	62·75	·769	58·25	·571
67·00	·956	62·50	·758	58·00	·560
66·75	·945	62·25	·747	57·75	·549
66·50	·934	62·00	·736	57·50	·538
66 25	·923	61·75	·725	57·25	·527
66·00	·912	61·50	·714	57·00	·516
65·75	·901	61·25	·703	56·75	·505
65·50	·890	61·00	·692	56·50	·494
65·25	·879	60·75	·681	56·25	·483

Of the oxalic acid consumed by the mud, one equivalent is converted into two equivalents of carbonic anhydride (CO_2) by the second equivalent of oxygen of the MnO_2 in the mud, the MnO_2 being at the same time reduced to MnO; another equivalent combines with the MnO thus formed; and the remainder combines with the protoxides originally contained in the mud. A cubic inch of mud was added to a solution of 50 grains oxalic acid; after heating the free acid neutralized 21·75 measures of caustic soda solution, each measure of which equals 0·63 grains of acid: 50 — (0·63 × 21·75) = 36·2975. An inch of the same mud had previously oxidized 61·5 grains of crystallized ferrous sulphate. As 61·5 . 36·2975 : : 100 : 59. Therefore by the table this mud contains 0·604 equivalent of bases per equivalent of MnO_2. The mud used in the above example would thus decompose and neutralize, per equivalent of chlorine liberated by it, 2·604 equivalents of HCl: one equivalent being converted into water and free chlorine, and another into water and chloride of manganese, by the MnO_2 of the mud, and the remaining 0·604 equivalent being neutralized by its "bases."

III. *For Total Manganese.*—A cubic inch of the mud is dissolved in the smallest practicable quantity of hydrochloric acid. The excess of acid employed is then neutralized, or nearly so, by soda or potash. The solution is then heated to boiling, and solution of bleaching-powder gradually added to it until a very slight purple coloration is perceived. All the manganese present has then been converted into MnO_2, except an exceedingly small quantity which is in solution as permanganate, and which is so minute that it may be neglected. The product is then thrown on to a filter, and the precipitate washed with boiling water until the wash-waters are colourless, or until they cease to colour iodide of potassium paper. The precipitate is then added (the filter may be added also) to a solution of protosulphate of iron in hydrochloric acid, and the excess of protosulphate determined by potassic bichromate, just as in determining the MnO_2 in the original mud. The quantity of protosulphate used should be greater, say by nearly half, than the quantity found to be oxidized by the original mud.

The practical value of a manganite mud depends largely upon the proportion in which the MnO_2 in it is combined with bases. The smaller the proportion of bases to MnO_2 in the mud, the less acid will it consume per given quantity of chlorine liberated by it. A mud the MnO_2 in which is combined with a full equivalent of bases will consume three equivalents of hydrochloric acid; but a mud the MnO_2 in which is combined with only half an equivalent of bases will consume only two and a half equivalents of hydrochloric acid per equivalent of chlorine liberated by them respectively. Fairly good working will yield regularly a mud not containing more than 0·6 equivalent of bases.

The "strength" of the mud, in the sense of the quantity of MnO_2 contained in a given volume of it, is however quite as important, in relation to acid consumption, as the proportion of bases in it.

Without using excess of it, and so losing MnO_2, it is extremely difficult to get the mud, whatever its strength, to neutralize the acid in the stills below the point at which there remains free from 6 to 8 ozs. of real HCl per cubic foot; and as the volume of the still-liquor, per given quantity of chlorine generated, is greater the more dilute the mud employed, it follows that the more dilute the mud which goes into the stills the greater must be the quantity of acid which comes out of them in the free state, not only having rendered no service, but having to be neutralized in the wells by limestone. A good mud should contain not less than 2·25 lbs. MnO_2 per cubic foot, as it runs out of the oxidizer, nor less than 5 lbs. per cubic foot as it runs into the stills.

The two tests which are of most importance are thus that for actual MnO_2 and that for bases. These should be made upon every batch. The test for total manganese has little practical utility, except in so far as it may be applied to manganese liquors, for purposes of stock-taking, or the like.

WELDON'S MAGNESIA PROCESS.—In the trial on a large scale chlorine was generated by the reaction upon each other of hydrochloric acid and manganite of magnesium. This operation was performed in a still, and was so managed as to yield an absolutely neutral still liquor, consisting of a mixed solution of chloride of magnesium and chloride of manganese.

This liquor was run out of the still into an iron pot, from which it was pumped up into an evaporating vessel, where it was boiled down until it had reached a temperature somewhat above 300° Fahr. Having attained that degree of concentration, it was run into a muffle furnace, in which its evaporation was continued to dryness, and the residue, piled up in heaps of thin cakes, was then gently heated with access of air. The chlorine of the two chlorides was thereby driven off, partly in the free state and partly as hydrochloric acid, manganite of magnesium being at the same time reproduced.

The chlorine obtained was partly strong, partly dilute. The proportion of the strong chlorine, generated in the still, to that of the weak chlorine, produced in the furnace, could be anything between one to one, and one to about four, at will.

When so working as to obtain strong chlorine and weak chlorine in about equal proportions, the quantity of liquor to be boiled down, per ton of total bleaching powder made, was about 105 cubic feet. As the proportion of the weak chlorine increased, the quantity of liquor to be boiled down diminished, until, when the proportion of the weak chlorine to that of the strong became as four to one, the quantity of liquor to be boiled down, per ton of total bleaching powder made, was only about 40 cubic feet.

The evaporation of the liquor down to the degree of concentration at which it should enter the furnace, was performed by the waste heat of the furnace itself.

The apparatus for this form of process was so fenced in that there was no loss of material in the solid state, as dust or otherwise; and a floor impervious to liquor, and sloping from all parts towards an iron pot into which any liquid spilt upon it cannot but run, precluded all risk of loss of material in the state of solution. A little fresh magnesia was required to be supplied from time to time, owing to the sulphuric acid in the hydrochloric acid forming sulphate of magnesium, which at suitable intervals had to be dissolved out from the furnace product; but the quantity of magnesia thus converted into sulphate was but slight, and the value of the sulphate was greater than the cost of the magnesia required to replace it.

The magnesia was purchased as "Greek stone," which is a very pure magnesite, or native carbonate of magnesium, and the manganite of magnesium was produced, in the first instance, by neutralizing with Greek stone an acid solution of chloride of manganese, and then treating the resulting mixed solution of chloride of manganese and chloride of magnesium as above described.

The chlorine, which left the furnace as acid, and which was collected as such in a condenser, was returned to the still, and thus the whole of the chlorine contained in the acid supplied to this process was obtained in the free state, partly strong and partly dilute. The strong portion was applied to the manufacture of bleaching powder in the ordinary chambers, the dilute portion to the production of bleaching liquor and potassic chlorate.

The magnesia process yielded therefore the *whole* of the chlorine contained in the acid employed, except to the extent of some loss from merely mechanical sources; there was absolutely no loss from a chemical source.

Plant for this process was erected in three factories, and very considerable quantities of chlorine were made by it; but in each case, when the apparatus fell out of repair, it was replaced by apparatus for the lime process.

DEACON'S CHLORINE PROCESS proposes to do away with the use of the manganese altogether, and to bring about the decomposition of the acid in a more direct manner.

It was known that cupric chloride, when strongly heated, splits up into cuprous chloride and free chlorine—

$$2CuCl_2 = Cu_2Cl_2 + Cl_2.$$

LAURENS has proposed to utilize this reaction for the production of chlorine on a large scale. It was further known that the cuprous chloride is transformed in a current of air into cupric oxychloride. This peculiarity led also to proposals for manufacturing chlorine, but it was never tried on a large scale.

When a mixture of gaseous hydrochloric acid and atmospheric air is passed over heated bricks, or other porous substances, water and free chlorine is obtained. OXLAND had attempted to make use of this reaction for obtaining chlorine on a manufacturing scale, but without success; very likely because the temperature at which the hydrochloric acid is

CHLORINE.

PLATE III.

DEACON'S DECOMPOSING TOWERS.

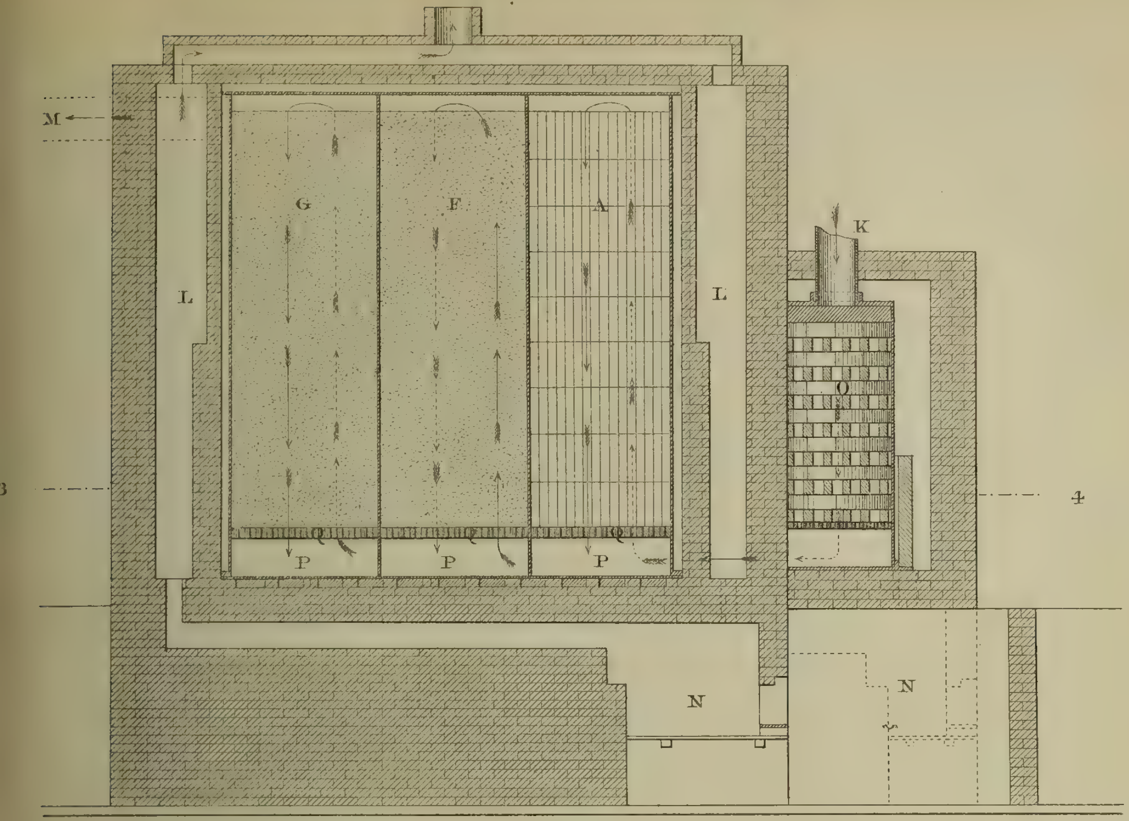


Fig. 1.

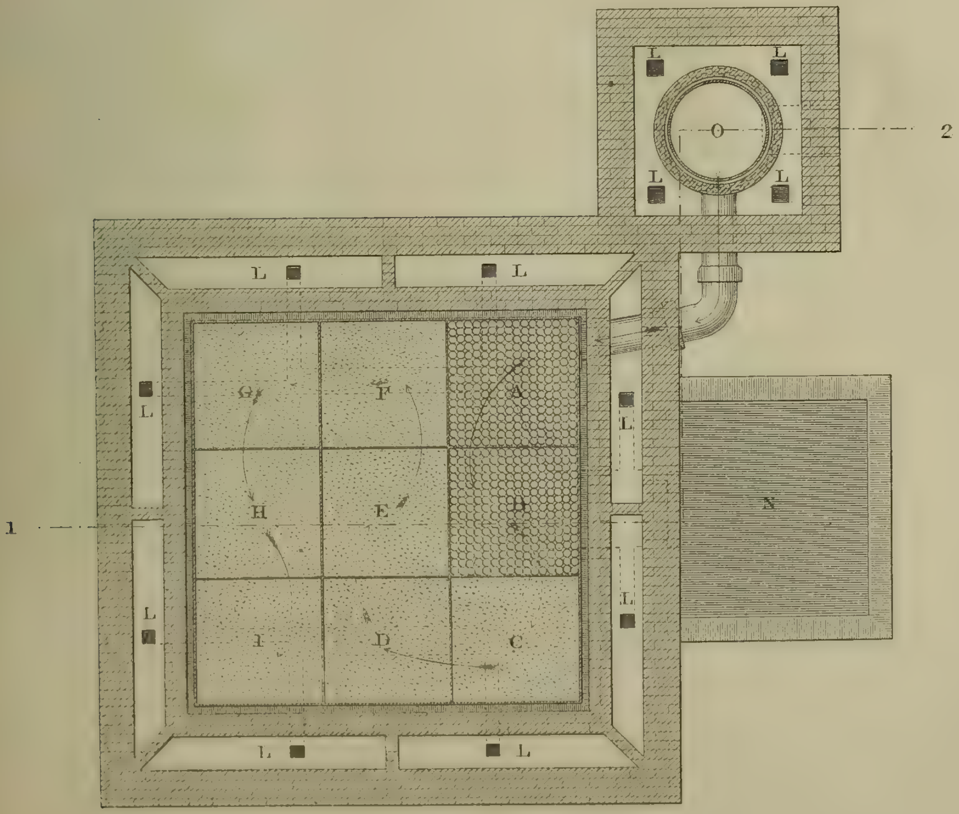


Fig. 2.

J. B. LIPPINCOTT & CO. PHILADELPHIA.

decomposed by oxygen is also that at which the newly formed water is decomposed by the chlorine liberated in the first part of the operation.

DEACON'S process is a combination of the two preceding ones, though H. DEACON seems to have reached his conclusions by wholly different channels. He found that the decomposition of a mixture of hydrochloric acid gas and atmospheric air takes place at a considerably lower temperature when the mixture is passed over heated copper, manganese, or lead salts (lead sulphate excepted), instead of bare bricks. Copper sulphate proved most efficient; porous bricks saturated with the solution of this salt and heated to a temperature between 700° Fahr. and 750° Fahr., burn the whole of the hydrochloric acid passed over them, together with excess of atmospheric air, to water and chlorine. An increase of temperature above 750° Fahr. proves injurious, inasmuch as at about 800° Fahr. cupric chloride is beginning to volatilize. The best temperature appears to be 625° Fahr. To increase the power of resistance to decomposition, as well as the efficacy of the copper sulphate, the addition of some glauber salt to the saturating solution has been proposed by Mr. DEACON.

The hydrochloric acid required in the process is got either directly from a soda furnace, or evolved from the aqueous solution. The latter way is the preferable one in small works, since it allows the keeping up of the regularity of the current, whilst the evolution of the hydrochloric acid in the soda furnace is in the beginning rather violent, and towards the end sluggish; to remedy this drawback in larger works, several furnaces are in succession employed for the production of the acid, so that if the current from one furnace begins to slacken, a second may be put into operation, &c. The hydrochloric acid gas, by whichever way obtained, is immediately mixed with a quantity of air, which contains more oxygen than required for liberating all the chlorine from the hydrochloric acid evolved, and passed through heated U-shaped cast-iron tubes, which impart to the mixture the necessary temperature. The composition of the gaseous mixture can always be ascertained by drawing (by means of a small air-pump) a measured volume of it, and passing it through a standardized solution of soda coloured by some litmus.

Fig. 1 (CHLORINE, Plate III.) represents a sectional elevation of one form of DEACON'S apparatus taken along the line 1—2, in Fig. 2; and Fig. 2 is a corresponding sectional plan taken along the line 3—4, in Fig. 1.

A, B, C, D, E, F, G, H, and I are a series of towers, constructed of iron or other material, through which the heated gases pass. The first or lowest portion of the first tower, or the whole of the first and second towers, are filled with the impregnated materials, arranged with vertical spaces (ordinary agricultural drain pipes of small bore are used for this purpose).

The other towers are filled with the impregnated materials in small pieces, spherical, flat, or mere shreds of burnt clay; the object being to obtain the largest possible surface over which to pass the gases in the smallest bulk, consistent with sufficient passage-room, without the necessity of an inconveniently great draught or propelling pressure. P P P are the vacant chambers or spaces into which the dust-like substance from the interstices in the towers above descends through the open grating or perforated plate, Q, and are therein collected and removed as required.

Preceding the towers is the apparatus, O, which DEACON terms the "heat regulator;" it is constructed of the same materials as the towers, and is filled with ordinary bricks, set open or reticulated. Its office is to prevent sudden changes in the temperature of the gases reaching the towers. The contents of this "heat regulator" either receive or impart heat as the gases increase or decrease in temperature, and to this extent "regulate" the temperature of the gases passing through it. This regulator is apart from the rest of the apparatus, to avoid transmission of heat by conduction.

It is easy by means of this apparatus to maintain a current of gases for twenty-four hours without skilled attendance, at temperatures varying not more than 60° Fahr. The temperature here, as in all other parts of the apparatus, is ascertained by metallic pyrometers. According to latest informations, however, there seems to be no absolute necessity for the use of this regulator, and Mr. DEACON thinks that the efficiency of his decomposing towers is not at all impaired by doing away with the regulating tower.

The towers and heat regulator may be surrounded with brickwork, in which are left the flues, L L, communicating with fireplaces, N N. These fires and flues are not necessarily to be used as sources of heat, but surround the towers with a heated envelop, so that the loss of heat from the towers themselves may be regulated as desired or prevented altogether. The temperatures of the various parts are ascertained by pyrometers, or in any convenient manner.

The heated gas enters the apparatus by the pipe K and leaves by M, following the course of the arrows through the nine decomposing towers, A, B, C, D, E, F, G, H, I. The dust which falls through the gratings, Q, Q, Q, into the receptacles, P, P, P, is iron chloride (or iron oxide, arising from the decomposition of the chloride), and comes from the U-shaped iron tubes in which the gases undergo the preliminary heating, and also from the iron pans in which the salt is treated with the sulphuric acid. The former source of iron chloride may be done away with by substituting for the heating in iron tubes, COWPER'S method of heating hot-blast for iron furnaces, viz., to heat a mass of brickwork, then cut off the fire to heat another mass, and pass the gaseous mixture of hydrochloric acid and atmospheric air through the heated mass; by the time that it is cooled the second mass will be heated, when the current of gas will be reversed, and so on. H. DEACON thinks, however, that by increasing the diameter of the iron pipes, and by carefully moderating the heating, the volatilization of the iron chloride in this place may be avoided. As to the second source of the chlorides of iron, the soda pans, the employment of leaden instead of iron pans, would to a great extent prevent the introduction of iron into the decomposing towers.

The gases are propelled by the aid of a chimney draft, and the speed of the current is measured by an anemometer devised by Dr. Hurter.

Mr. Deacon has of late proposed to unite all the nine towers into one space, *i.e.*, to do away with the walls of partition, and also to substitute ordinary brick-pieces for the drain pipes. Indeed, this plan has been tried already in Kuhnheim's factory, at Berlin, and the working has gone on for several months without interruption.

Without entering at length into the theory regarding the action of the copper salt, we may give the conclusions which Deacon draws from the experiments which he has made in conjunction with Dr. Hurter:—

(1.) That with the same mixture of gases, and at the same temperature, the amount of hydrochloric acid decomposed by the aid of a molecule of the copper salt in a given time, depends upon the number of times the molecules of mixed gases are passed through the sphere of action of the copper salt. Conversely, that the activity of a molecule of copper salt depends upon the speed with which fresh matter is presented to, and the products are removed from it.

(2.) That in long parallel tubes of the same diameter, the number of opportunities of action in the same time is nearly the same at all velocities of the current of gas.

(3.) That in long parallel tubes of different diameters, the number of opportunities of action of each molecule of copper salt is the same when the velocities of the currents of gas are in inverse proportion to the squares of the tubes' diameters.

(4.) That in porous matters the opportunities of action increase with increased velocities of the current of gas in nearly direct proportion.

(5.) That, other conditions remaining the same, the percentage of hydrochloric acid decomposed in any given time varies with the square root of the proportionate volume of oxygen to hydrochloric acid. Conversely of course, the percentage of oxygen used varies with the square root of the proportionate volume of hydrochloric acid to oxygen.

(6.) That the cupric chloride formed bears no definite proportion to the quantity of chlorine produced.

(7.) That as the sphere of action includes molecules not in contact with the copper salt, therefore hydrochloric acid must be decomposed under circumstances where the union of either element with the copper salt is impossible, *i.e.*, that the decomposition must in part, if not entirely, be caused by the resultant of the forces engaged, and therefore direct from $2HCl + O$ to $H_2O + 2Cl$.

The gaseous mixture of hydrochloric acid and air consists, on leaving the decomposing apparatus at M, of chlorine, water, nitrogen, unconsumed oxygen, and undecomposed hydrochloric acid. The colour of the resulting gases gives a good indication of the success of the decomposition; and the proportion of hydrochloric acid is easily ascertained when desired, by a finger-pump, drawing known quantities at each stroke through a normal alkaline solution coloured with litmus. The greater the number of strokes required before the blue colour is changed to red, the more air and less acid gas is present, and *vice versa.* The hydrochloric acid is separated from the mixture by conducting it, after previous cooling, through water; the water of the mixture is fixed by sulphuric acid, which runs down over coke in a tower, and through which tower the mixed gases are passed. The gases thus purified are ready for the making of bleaching powder. Of course, if an aqueous liquid is to be saturated with chlorine, as is the case in the preparation of chlorate of potash, there is no need for drying the gases.

An objection made to this process was that volatilization of the copper salt would soon diminish the decomposing efficiency of the bricks, and finally stop the operation altogether. To this objection Mr. Deacon replied by stating that at the temperature mentioned above, at which the decomposition of the hydrochloric acid takes place, no appreciable quantity of copper chloride volatilizes. Recently he has devised a remedy for even this small loss. Steam is passed over the bricks, after the furnace has been cooled down to about 220° Fahr.; the steam dissolves the copper sulphate in the interior of the porous brick pieces, and this solution, by flowing over the outer surfaces of the clay pieces, deposits there a new layer of copper sulphate.

The next point that was urged against the practicability of Deacon's process was the great bulk of the gases evolved, and the necessity of having to construct enormously large chambers for the preparation of bleaching powder.

To counteract this disadvantage, H. Deacon passes the gas through a series of chambers, in which the first contains nearly finished bleaching powder, the next less saturated lime, and so on, until the last is filled with lime as usually slaked for the manufacture of bleaching powder. In this way the gas volume richest in chlorine comes in contact with lime nearly saturated with chlorine, whilst the gas which has been deprived of almost all its chlorine passes over slaked lime that has not yet been in contact with any chlorine.

That the bleaching powder made from chlorine obtained according to Deacon's method is of great strength, and that it is so with some regularity, may be seen from the following table of chamber tests for fourteen consecutive working days:—

		Strength.			Strength.
July	14	36·0	July	22	34·3
"	15	34·8	"	"	36·5
"	"	36·1	"	24	36·8
"	17	36·4	"	"	37·5
"	"	36·0	"	25	36·1
"	18	37·2	"	"	36·7
"	"	37·9	"	"	36·8
"	19	37·2	"	26	36·2
"	"	37·0	"	"	36·9
"	20	37·9	"	27	36·9
"	"	36·7	"	"	35·5
"	21	36·0	"	28	37·2
"	"	35·3	"	"	37·0
"	"	37·7	"	29	36 75

Another proposition of Mr. DEACON for the production of chlorine was to pass a mixture of air (or oxygen) and vapour of anhydrous sulphuric acid (SO_3) over heated sodium chloride. This proposition has been modified and generalized by DE LALANDE and PRUD'HOMME. They find that when a mixture of silica and the chloride of an alkali metal, alkaline-earth metal, or earth metal, is heated to redness, and subjected to the action of a current of air or oxygen, chlorine is evolved, and the chloride is converted into a silicate—

$$SiO_2 + 2NaCl + O = Na_2SiO_3 + Cl_2.$$

On treating the resulting silicate with a mixture of hydrochloric acid and oxygen, the silicate is decomposed, and the original chloride reproduced—

$$Na_2SiO_3 + 2HCl = SiO_2 + 2NaCl + H_2O.$$

In this manner a continuous evolution of chlorine can be secured.

The water formed in the second reaction leads to two secondary reactions:—

(*a*) The water is decomposed by the chlorine—

$$H_2O + 2Cl = 2HCl + O;$$

(*b*) The chloride is decomposed by the water—

$$2NaCl + H_2O = Na_2O + 2HCl.$$

The silica may be replaced by boric, stannic, and phosphoric acids, alumina, pumice stone, and pieces of brick, with quite as good results.

The temperature required in these decompositions is somewhat higher than in DEACON'S process.

A modification of DEACON'S copper salt method has been patented by W. HENDERSON. According to this, a mixture of hydrochloric acid gas and air are passed over bricks made of iron oxide and a little clay, heated to about 400° Fahr.

The importance of the bleaching industry gave occasion to a great many other propositions for the production of chlorine; but since most of them are as yet far from practical realisation, we must pass them over.

The following information as to the prices of bleaching powder has been supplied by Mr. R. C. CLAPHAM, and may be interesting to manufacturers:—

In 1805.................	£120	0	0	per ton.
" 1810,.................	84	0	0	"
" 1815, ...	80	0	0	"
" 1820,.................	47	0	0	"
" 1825,.................	27	0	0	"
" 1830,.................	23	0	0	"
" 1832,.................	21	0	0	"
" 1835..................	23	10	0	"
" 1840,.................	21	0	0	"
" 1846,.................	18	10	0	"
" 1850,.................	13	15	0	"
" 1855,.................	10	15	0	"
" 1857,.................	13	10	0	"
" 1860,.................	11	0	0	"
" 1868,.................	10	12	0	"

Chlorometry.—The value of bleaching powder depends upon the quantity of chlorine which may be liberated from it under the influence of an acid, and hence the estimation of this quantity is of importance to the bleacher.

Chlorine, whether in the free state, or combined with weak alkalies or caustic lime, having the property of destroying colouring matter of an organic nature, this reaction was, from the first, resorted to as a means of determining the commercial value of its compounds as bleaching agents. One part of best commercial indigo blue is dissolved in nine parts of concentrated sulphuric acid, then diluted to any required point, and the quantity of chlorine required to discharge the colour ascertained by a known weight of chlorate of potash, decomposed by hydrochloric acid—the chlorine thus evolved absorbed by potash, as in the case of manganese, and this solution added from a graduated test glass to a certain amount of the coloured liquor. Sometimes this species of testing is performed in the following manner:—The sample of bleaching powder is weighed and dissolved in a known volume of water, then the standard measure of strongly acidulated solution of indigo poured into it till the colour ceases to be destroyed. Unless the operator mixes the tests in a stoppered bottle, a loss of chlorine will result from the action of the strong acid solution upon the lime compound. As a check upon the first determination, a second estimation should be made, in which case the whole of the solution required in the preceding instance should be measured off in a tube graduated from below upwards, and added to within one or two divisions to the bleaching liquor at once, and the whole well agitated. After the greater part of the chlorine has been thus combined, the traces still remaining may be easily absorbed by the residuary portion of the indigo test solution. It is more convenient to add the bleaching solution to the indigo until it loses the colour.

But the indigo test is very unsafe. In the first place, the indigo solution decomposes spontaneously by standing, even when kept in well stoppered bottles and in the dark. Next, it is very difficult to ascertain when the reaction is complete, for the yellow colour, resulting from the decomposition of the indigo mixing with the original blue colour of the solution, produces a green tint, which interferes with the correctness of the observation.

GAY-LUSSAC was the earliest to devise an accurate method. It is based on the property of a solution of arsenious acid, As_2O_3, in hydrochloric acid to become oxidized to arsenic acid, As_2O_5, in the presence of chlorine and water. The reaction may be represented by the equation—

$$As_2O_3 + 2H_2O + 4Cl = As_2O_5 + 4HCl.$$

The reaction is very rapid. If organic substances, capable of being decolorised by the action of chlorine, are present while it is taking place, the colour is not destroyed so long as any portion of arsenious acid remains unconverted into arsenic acid; but as soon as the last portion of the arsenious acid has been oxidized, the liquor is instantly decolorised, and this reaction at once indicates the end of the experiment.

Taking the equivalent number of arsenious acid = 198, that of chlorine = 35·5, it is evident that

198 grains of arsenious acid will correspond to $4 \times 35{\cdot}5 = 142$ grains of chlorine; or, which is the same, 139·4366 grains of arsenious acid will correspond to 100 grains of chlorine.

Take, therefore, a certain quantity of the arsenious acid of commerce, reduce it to powder, and dissolve it in hot diluted hydrochloric acid; allow it to crystallize therefrom, wash the crystalline powder with cold water, dry it well, reduce to fine powder, and of this put 139·44 grains into a flask, add thereto about 3 ozs. of pure hydrochloric acid, one that is absolutely free from sulphurous and nitric acid, and which has been, before addition, diluted with three or four times its bulk of water, and keep the whole boiling until all the arsenious acid has dissolved. Pour now the solution into a glass cylinder graduated into 10,000 grains-measures, rinse the flask with water, pour the rinsings into the cylinder, and fill it up with more water to the mark 10,000. It is clear that 1000 measures of this solution contain 13·944 grains of arsenious acid, which require to their conversion into arsenic acid 10 grains of chlorine.

A sample of 100 grains of the bleaching powder to be examined is then weighed, triturated with some water in a mortar, and to the turbid milky solution so much water is added that 10 grain-measures of the solution—representing one degree—shall contain 0·5 grains of bleaching powder.

Pour now 1000 grains of the arsenious acid test liquor into a large beaker, add to it a few drops of sulphate of indigo solution in order to colour it distinctly blue, shake the glass so as to give a circular motion to the liquid, and while it is whirling round pour gradually into it the chloride of lime liquor, watching attentively the moment when the blue tinge of the standard acid is destroyed.

The quantity of available chlorine in the sample is then determined in the following manner:—

Let us suppose that it required 90° of the bleaching powder liquor to destroy the blue colour of the 1000 grain-measures of the acid test liquor, then it is evident that these 90° contained the 10 grains of chlorine necessary for the complete oxidation of the 13·944 grains of arsenious acid in the 1000 parts of test liquor; and since each degree contains 0·5 grains of bleaching powder, the 90° must have 45 grains, and consequently the 10 grains of chlorine were in these 45 grains of bleaching powder. A simple proportion leads now to the percentage,—

$$45 : 10 = 100 . x$$

$$x = \frac{10 \times 100}{45} = 22\tfrac{2}{9} \text{ per cent. of available chlorine}$$

was in the sample investigated.

It is necessary to pour the bleaching powder liquor into the acid test liquor, because otherwise the hydrochloric acid of the acid test liquor would disengage suddenly more chlorine than the arsenious acid could absorb; some chlorine would escape, and thus render the result incorrect.

Runge, and after him Graham, have made ferrous sulphate, $FeSO_4$, the basis for the standard solution. This salt is transformed by chlorine, in the presence of free sulphuric acid, into the ferric sulphate, thus:—

$$FeSO_4 + H_2SO_4 + 2Cl = Fe_2(SO_4)_3 + 2HCl.$$

To obtain the iron salt in a pure state, so much fine pianoforte wire is dissolved in not too dilute sulphuric acid as will nearly neutralize it; the liquor is then filtered and set aside to crystallize, care being taken to keep it slightly acid, and a few fragments of the wire suspended in it, to prevent oxidation by the hydrogen evolved. In this case the crystals are well-defined oblique rhombic prisms of moderate size; but if it be desired to obtain them of less size, the slightly acid concentrated hot lye is filtered into strong alcohol, when the salt precipitates in a finely clear pulverulent state. When the crystals are separated from either of these menstrua, and dried between folds of blotting paper, they have the composition expressed by the formula, $FeSO_4 + 7H_2O$, the equivalent of which is 276. Now it has been shown that two equivalents of chlorine, *i.e.*, 71 parts by weight, will oxidize one equivalent, *i.e.*, 278 parts, of the crystallized protosalt; and, based upon these numerical relations, it is easy to prepare standard solutions and then to make the necessary calculations.

The indicator in this case is potassic ferricyanide, which salt gives a blue precipitate with any protosalt of iron. The progress of the oxidation of the iron protosulphate is, therefore, measured by dipping the end of a stirring rod into the standard liquor, after it had been well shaken on the addition of the sample liquor, and bringing the rod end in contact with drops of a concentrated solution of potassic ferricyanide, dotted on a white porcelain slab; when the colouring produced appears greenish yellow, the oxidation of the iron protosulphate into sulphate has become complete.

Penot has modified Gay-Lussac's test by bringing about the oxidation of the arsenious acid in an alkaline, instead of in an acid solution, and he employs a test-paper moistened with starch paste, containing iodide of potassium, to show when the reaction is completed. A solution of 139·44 grains of purest arsenious acid in a few ounces of water is prepared, and about 700 grains pure carbonate of soda (specially free from every trace of sulphide or hyposulphite) are added to it. The mixture is boiled until the solution has become clear, filled into a standard cylinder, which, after the cooling of its contents, is filled up with water to 10,000 grain-measures.

The starch test is prepared by boiling 3 parts of starch with 500 of water, and afterwards adding 1 part of iodide of potassium. Slips of filtering paper are dipped into the mixture and used whilst still damp, in which state they are far more sensitive than when dried.

The bleaching-powder solution is prepared as in Gay-Lussac's method. Of this solution 1000 grains are, immediately after thorough shaking up, measured out with a pipette, and transferred into a beaker; a graduated burette having been filled up to the proper height with the soda arsenite liquor, its contents are gradually run into the bleaching powder solution, till a drop of this taken out with a glass rod ceases to produce any coloration upon a piece of the starch-test paper. The operation is then completed.

If the burette contains 1000 grains divided into 100 parts, 1 part corresponds to 1 per cent. of chlorine, as can easily be seen from the equation and the calculations already given.

Bunsen recommends to add the iodide of potassium to the bleaching-powder liquor, to acidulate the mixture with hydrochloric acid, and to run the soda arsenite solution into it till only a yellow tint shows itself. A little starch paste is now added, and the arsenite solution cautiously introduced drop by drop till the blue colour just disappears. Of course, the solutions are all standardized.

Since the starch paste is apt soon to decompose, **Mohr** advises to add to it a little chloride of zinc.

G. Lunge states that the same piece of moist test-paper may serve for any length of time, since the spots produced in testing soon disappear (usually after about twenty-four hours), on leaving the paper exposed to the influence of the air, only providing against its becoming covered with dust.

G. E. Davies proposes to use glycerin as solvent for the arsenious acid. His standard solution is:—13·95 grains of arsenious acid in 40 cc. of glycerin, and filled up to 1 litre. Every 10 cc. corresponds to 0·1 grain of chlorine. Indigo sulphate solution is used as indicator, and the bleaching liquor is run into the glycerin solution, until the blue colour of the latter is changed to a brownish yellow.

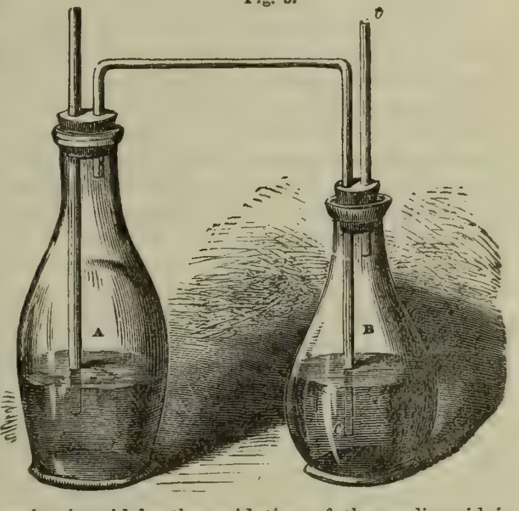
J. Smyth, jun., thinks the use of the milky solution of bleaching powder in chlorometry unsatisfactory, and recommends, for the purpose of obtaining a clear solution, the addition of 20 grammes of soda-crystals ($Na_2CO_3 + 10H_2O$) to 10 grammes of bleaching powder, and after filtering out the precipitated carbonate of lime (which is known to be washed when it no longer discharges the colour of dilute indigo sulphate), making up the filtrate with water to 1 litre of fluid.

Manganese.—This mineral occurs in combination with baryta, silica, iron, potash, lime, magnesia, cobalt, &c. It is found in Germany, Spain, France, Belgium, and Holland, and smaller quantities are raised in England, Piedmont, America, and Austro-Hungary. The difference in the composition of the various ores is very great, but the samples met with in commerce are usually mixtures of different ores. The following is, after G. **Tissandier**, the composition of some of the commercial manganese ores:—

	From Germany.	From Spain.	From Mexico.	From Chili.
Water,...............	1·14	2·20	1·00	3·22
Silica,...............	14·05	9·25	5·85	4·27
Manganese peroxide,..	71·21	74·10	80·24	61·50
Iron oxide,...........	10·39	14·21	6·18	30·41
Alumina,.............	1·21	0·12	1·80	0·60
Calcium carbonate,....	2·00	0·12	4·93	trace
	100·00	100·00	100·00	100·00

The best and simplest method for determining the amount of peroxide in a sample of manganese ore is that of **Fresenius** and **Will**. It consists in reducing it to very fine powder, weighing out a certain portion, and introducing it into the flask, A, in the annexed Fig. 5; two and a half times the weight of the manganese are then taken of neutral oxalate of potash, and about two ounces of water are poured into the same bottle, after which the flask, B, is filled to about two-thirds of its capacity with strong sulphuric acid; both flasks are next closed by the doubly perforated corks, into which the tubes are inserted, as represented in the figure. The apparatus is now wiped dry, and placed upon the pan of the balance, and the weight noted; the tube, *a*, is then closed by a piece of wax, and suction is applied at the tube, *b*; by this means a partial rarefaction of the air in the flasks is produced, and on withdrawing the mouth from *b*, the influx of air forces a portion of the acid over through *c* into A, which, coming in contact with the manganese and potash salt, evolves carbonic acid by the oxidation of the oxalic acid in the oxalate.

Fig. 5.



This gas escapes through the tube, *c*, and the sulphuric acid in the flask, B, and finally by the short open tube into the air. When the generation of the gas takes place but feebly, a fresh quantity of sulphuric acid is forced over, and the operation thus continues till all the black mineral is decomposed, and no more carbonic acid is generated, even in the presence of an excess of sulphuric acid. The wax stopper is then removed from the tube, *a*, and suction applied at *b*, till all the carbonic acid in the flask, A, is carried off. A careful wiping of the flasks is now necessary, after which they are weighed. The results of the former and the latter weighings differ directly according to the weight of carbonic acid which has been formed from the oxalic acid.

From this it is clear that every equivalent of peroxide of manganese operated upon in the way described, gives rise to two equivalents of carbonic acid; and as the atomic weight of these is the double of 44—this being the equivalent of the dry and pure gas—or 88, which is almost the equivalent weight of the peroxide, which in reality is 87, it is evident that the weight of the carbonic acid ascertained is the same as that of the pure peroxide required to produce it. In testing manganese in this way, it is necessary that the tubes and corks should fit air-tight, and that the oxalate should be neutral and free from carbonate. The carbonic acid gas, as it passes through the sulphuric acid, is divested of any moisture which might have accompanied it from the flask, A. Sometimes oxalic acid is used instead of oxalate of potash; but as it gives off carbonic acid immediately on coming in contact with the manganese and water, more or less of which escapes before the apparatus is weighed, the results are not so accurate as when the oxalate of potash is used.

The sample of manganese must, previous to this treatment, be digested with some dilute nitric acid, in order to expel the carbonic acid of the lime and magnesia carbonates, which may be present in the ore.

A modification of this method has been proposed by MOHR. It is executed in the following manner:—Three grammes of the finely-powdered and dried manganese ore are mixed in a small glass flask with a little water, and enough sulphuric acid to render the whole mass perfectly fluid. This flask and a porcelain capsule containing about nine grammes of crystallized oxalic acid, are now placed in one scale of the balance, and brought into equilibrium by a basin of sand or small shot. The oxalic acid is now thrown into the flask, where it immediately begins to reduce the binoxide of manganese under evolution of carbonic acid. To accelerate this decomposition, it is good to give the flask a circular horizontal motion, until the evolution of the carbonic acid has ceased, and the mass from black, which it was, has become light-coloured. The empty porcelain capsule and the glass flask are now again placed on the balance, and so much weight placed with the capsule as to restore the equilibrium. The weight required to effect this is equal to the weight of the peroxide of manganese in the ore, because one equivalent of peroxide = 87, when treated with oxalic and sulphuric acids, cause the evolution of two equivalents of carbonic acid = 88; therefore, practically, one part by weight of peroxide of manganese is indicated by one part of carbonic acid.

Now, as 3 grammes of ore have been employed for the above experiment, it follows that the amount of carbonic acid lost, divided by three, indicates the amount of peroxide of manganese in one gramme of the ore; and by multiplying the latter number with 100, the percentage of the peroxide is obtained. The error produced by the loss of water in this method does not signify for most practical purposes, but may be remedied by closing the flask with a cork in which a glass tube filled with dry chloride of calcium is fastened. In this case, however, the carbonic acid contained in the flask when the experiment is finished must be removed by suction.

In estimating the value of a sample of manganese ore for the production of chlorine, the quantity of iron contained in the ore must not be left out of sight, since it will withdraw a certain proportion of hydrochloric acid from the production of free chlorine.

CHLOROFORM.—See CHLORAL AND CHLOROFORM.

CITRATE OF MAGNESIA.—See MAGNESIA, GRANULAR EFFERVESCENT CITRATE OF.

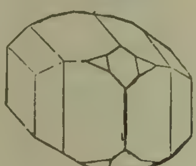
CITRIC ACID.—*Acide citrique*, French; *Citronsäure*, German; *Acidum citricum*, Latin ($C_6H_8O_7$).—The first account which we have of any attempt to purify lemon juice is that of Georgius, a Swedish chemist, who in 1774 proposed to concentrate it by exposure to a freezing temperature. The frozen portions, consisting of ice and mucilage, were then removed, and the operation repeated until the liquid was reduced to about one-eighth of its original bulk. In 1784 SCHEELE succeeded in obtaining citric acid in a crystalline state, and proved that it was distinct from tartaric acid. Citric acid exists ready formed in the acid juice of many fruits, as the lemon, orange, lime, cranberry, and whortleberry; also in the currant, gooseberry, cherry, &c., mixed however with a considerable proportion of malic acid.

Citric acid is especially abundant in lemon and lime juice, from which it may be procured in the following manner:—The juice is sometimes submitted to an incipient fermentation, with the view of separating the mucilage, which is deposited, and the supernatant clear liquor is then poured off for use, or the juice is heated, and clarified by white of egg; it is then saturated at a temperature near its boiling point with very finely-powdered carbonate of lime, which is added in small portions as long as effervescence takes place, 16 parts of the juice requiring about 1 part of the earthy carbonate. It has been noticed, that owing to the formation of an acid salt of lime, the elimination of carbonic acid ceases before the whole of the citric acid is precipitated; in order to effect which, small quantities of hydrate of lime may be added until the liquid no longer exhibits an acid reaction; it is then permitted to cool, and the citrate of lime collected upon a strainer, and well aspersed with warm water, until the percolating liquor runs off clear and colourless. The contents of the strainer are then decomposed by placing them in a hot mixture of 1 part of strong sulphuric acid diluted with 6 parts of water. Care must be taken in this part of the process to mix the lime salt intimately with the acid by constantly stirring the liquid. When the mixing is completed, the whole is left at rest for several hours until the decomposition of the citrate is terminated; the clear solution is then decanted from the deposited sulphate of lime, which is washed with a little cold water. The citric liquor may now be evaporated until it acquires the spec. grav. 1·13, after which steam-heat or a water-bath must be used, so as gradually to expel aqueous vapour. As soon as the liquid becomes sirupy, or a pellicle forms on its surface, the heat must be withdrawn, to prevent decomposition. In about four days the mother liquor is poured off the crop of crystals, and evaporated with the same precautions as before, and this is repeated until *clean* crystals are no longer obtained, the remaining liquor is then diluted, and submitted to the same treatment as the original lemon juice. Several solutions and recrystallizations are required to obtain the citric acid pure; in fact, it is occasionally necessary to filter it through animal charcoal.

Currants or gooseberries may be employed as a source of this acid: they are to be bruised, the expressed juice fermented, and then distilled to obtain the alcohol; the residue is saturated with chalk, and the citrate of lime decomposed by sulphuric acid—100 lbs. of the fruit yield 10 lbs. of spirit and 1 lb. of citric acid.

This acid occurs in commerce under the form of regular transparent colourless prisms, belonging to the right prismatic or trimetric system (Fig. 1). Their composition may be represented by the formula, $C_6H_8O_7 + H_2O$, but a boiling concentrated solution of the acid, as it cools, deposits crystals of a different form, which, according to some chemists, have the composition $2C_6H_8O_7 + H_2O$. Citric acid has an intensely acid but agreeable taste, and dissolves in ·75 of its weight of water at 15° C., and in half its weight at 100° C. The crystals also dissolve in alcohol, but are insoluble in ether.

Fig. 1.



Crystallized citric acid effloresces in warm dry air, and at 100° loses all its water of crystallization, leaving the dry acid of the composition, $C_6H_8O_7$.

6 atoms of Carbon,...........	72	..	37·50
8 atoms of Hydrogen,.........	8	..	4·17
7 atoms of Oxygen, ...	112	..	58·33
	192	..	100.00

Citric acid is a tribasic acid, and its constitution may be represented as $(C_3H_4)\left\{\begin{matrix}OH\\(COOH)_3,\end{matrix}\right.$

or, $\left\{\begin{matrix}CH_2.COOH\\CH.COOH\\CH_2.COOH,\end{matrix}\right.$ in which the hydrogen of one or more of the COOH groups may be replaced by a metal such as potassium, giving rise to three series of salts, $C_6H_5O_7KH_2$, $C_6H_5O_7K_2H$, $C_6H_5O_7K_3$. A great number of these have been examined and described, but none of them, except the neutral calcium salt, $(C_6H_5O_7)_2,Ca_3 + 4H_2O$, possesses any special interest for the technical chemist.

If a few drops of a solution of citric acid be added to lime water, it produces no apparent effect until the mixture is boiled, when a white precipitate of calcium citrate is produced, which is soluble in acids without effervescence.

Decompositions.—The action of heat on citric acid has occupied the attention of many chemists, among whom may be mentioned Lassaigne, Dumas, Berzelius, and Robiquet, the results of whose experiments were apparently contradictory and irreconcilable. The researches of Crasso, however, cleared up and reconciled the inconsistencies of his predecessors. According to this chemist, crystallized citric acid, when exposed to heat, exhibits four stages of decomposition.

When heated in a retort, it first melts and boils, giving off its water of crystallization. At a higher temperature, about 175° C., decomposition takes place; acetone distills over, accompanied by a copious evolution of carbonic oxide and carbonic anhydride, and at this stage *aconitic acid* remains in the retort. On continuing to apply heat, the aconitic acid is decomposed, carbonic anhydride being disengaged, whilst *itaconic acid* condenses in oily striæ on the neck of the retort. When cold, this oily liquid solidifies to a mass of crystals, which, on being repeatedly distilled, lose water and become converted into *citraconic anhydride*, an oily substance which no longer solidifies on cooling. The changes which citric acid successively undergoes in these operations may be represented by the following equations:—

$$\overset{\text{Crystallized Citric Acid.}}{C_6H_8O_7 + H_2O} = \overset{\text{Dry Citric Acid.}}{C_6H_8O_7} + H_2O.$$

$$\overset{\text{Citric Acid.}}{C_6H_8O_7} = \overset{\text{Aconitic Acid.}}{C_6H_6O_6} + H_2O.$$

$$\overset{\text{Aconitic Acid.}}{C_6H_6O_6} = \overset{\text{Itaconic Acid.}}{C_5H_6O_4} + CO_2.$$

$$\overset{\text{Itaconic Acid.}}{C_5H_6O_4} = \overset{\text{Citraconic Anhydride.}}{C_5H_4O_3} + H_2O.$$

The acetone and carbonic oxide observed in the second stage of the decomposition are probably formed by a splitting up of the aconitic acid, thus:—

$$\overset{\text{Aconitic Acid.}}{C_6H_6O_6} = \overset{\text{Acetone.}}{C_3H_6O} + 2CO_2 + CO.$$

Itaconic acid is also produced when citric acid is heated with water for several days in sealed tubes to a temperature of 160° C.

Fungoid growths make their appearance in an aqueous solution of citric acid when it is kept for any length of time, and when mixed with chalk and exposed to a temperature of about 25° C., with a little yeast, fermentation sets in, and the calcium citrate becomes converted into acetate and butyrate. Sulphuric acid, at a temperature of 30° C., eliminates water from the acid, and carbonic oxide is evolved; at a higher temperature, acetone and carbonic anhydride are produced. Fused with caustic potash, citric acid is decomposed into oxalic and acetic acids, thus:—

$$\overset{\text{Citric Acid.}}{C_6H_8O_7} + \overset{\text{Water.}}{H_2O} = \overset{\text{Oxalic Acid.}}{C_2H_2O_4} + \overset{\text{Acetic Acid.}}{2C_2H_4O_2}.$$

When citric acid is heated with peroxide of manganese mechanically suspended in water, carbonic anhydride and acetic acid are formed; with red oxide of mercury it produces effervescence, with the production of acetic acid; and with chloride of gold reduction occurs without any evolution of gas.

Citric acid is readily oxidized by potassium permanganate to acetone and carbonic anhydride. According to Chapman and Smith, however, a strongly alkaline solution of potassium permanganate is reduced by the citrate only to the state of manganate, the liquid acquiring a permanent green colour; tartaric acid, under similar circumstances, completely destroys the colour, thus furnishing a means of distinguishing between these two acids. Bromine readily decomposes potassium citrate, carbonic anhydride is given off, and bromaform, $CHBr_3$, and a crystalline body, bromoxaform, $C_3HBr_5O_2$, are produced. With chlorine the action is more complicated, various oily substances besides chloroform being produced.

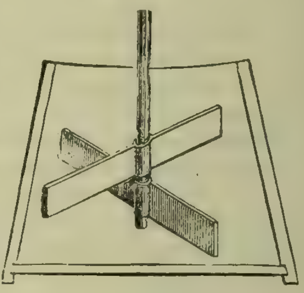
MANUFACTURE.—This acid is prepared by a few firms from the juice of lemons, which is imported in a concentrated state, principally from Sicily and the south of Italy, in casks containing each from 105 to 110 gallons. The bergamot juice of South Italy is also imported for this purpose. Lemon juice is often adulterated with acids, common salt, &c., the former of which, were it tested by the amount of alkali a certain quantity would neutralize, would give a good percentage; while the latter is added to increase the specific gravity, since in many establishments it is examined by means of the *citrometer*—which is nothing more than a hydrometer marked for this particular purpose—and thus the same object is attained. The density of the juice is also often rendered much greater by the carbonization which has occurred during its evaporation; for these reasons, and also on account of the variation in the amount of earthy salts and of saccharine matter, the specific gravity test can scarcely give an approximate result as to the real quantity of acid contained in the sample. For the reasons above mentioned, even the neutralization of a certain weight of alkaline carbonate is a doubtful means of estimation, unless the juice has been previously examined for other acids, and their percentage ascertained.

Sicilian lemon juice is expressed from the damaged fruit, windfalls, &c., and in its unconcentrated state contains between 8 and 9 ounces of free citric acid per gallon. The quantity of free acid in the juice expressed from the fine lemons imported to this country is much higher, however, being between 10½ and 12½ ounces per gallon. The Sicilian juice, after being expressed, is boiled down in copper pans until it has a density corresponding to about 60° on the citrometer, or specific gravity 1·234, each degree on the citrometer corresponding to an increase in the specific gravity of ·004. It is then a dark brown syrupy liquor, containing free acid equivalent to about 64 ounces of citric acid per gallon, or 32 per cent., and besides this, 6 or 7 ounces of combined acid. Of the total acids present, an amount varying from 5 to 11 ounces in various samples of juice, consists of organic acids other than citric.

The process followed for its manufacture on the large scale does not essentially differ from that of preparing small quantities, except as regards the utensils.

The juice to be operated upon is conducted into the decomposing tuns by tubular pillars provided with stopcocks, which communicate with cisterns in the apartment above, into which the contents of the casks are emptied. When the tuns are nearly filled, a sufficient quantity of carbonate of lime is added, previously well ground, and the agitators are kept in constant motion by the machinery above the tun, worked by steam power, until the precipitation of the acid as calcium citrate is completed. Fig. 2 is a section of the tun, showing the agitators in the interior. The mixture, however, is always distinctly acid, even when a large excess of chalk has been added. This was formerly attributed partly to the presence of acid calcium citrate, and partly to a similar alumina compound, but Mr. R. WARRINGTON has found that there is no difficulty in neutralizing pure citric acid with chalk in the cold, even when alumina is present. A solution of phosphoric acid, or phosphate of iron in citric acid, however, cannot be neutralized by chalk; and as the concentrated lemon juice invariably contains a good deal of phosphoric acid and a little iron, it is probable that the difficulty experienced in neutralizing the acidity must be attributed to the presence of these substances, or at least to a great extent. The whole of the acid may, however, be precipitated by the addition of milk of lime until the mixture becomes neutral, but the mucilaginous matters thrown down at the same time interfere so much with the subsequent operations, that it is far more advantageous not to add the lime.

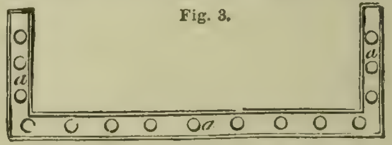
Fig 2.



When the action is terminated, the precipitate is allowed to subside, and the supernatant liquid is drawn off. The citrate of calcium is then washed by stirring it up with water, allowing it to settle, and again drawing off the clear liquor; but, as it is very liable to ferment and decompose, especially in warm weather, the washing must be carried on as rapidly as possible. It is now ready for decomposition by sulphuric acid, 9 parts of oil of vitriol diluted with 56 parts of water being used for every 10 parts of the citrate. When this has been done, the whole contents of the tun are run off by pipes into vats, which retain the sulphate of lime, while the solution of citric acid flows into steam evaporators, where it is concentrated.

One of these evaporators is shown in section in Fig. 3, in which the two inner lines represent the lining of lead, and the outer ones the exterior casing of wood, while the circles indicate steam-pipes in the interior.

Fig. 3.

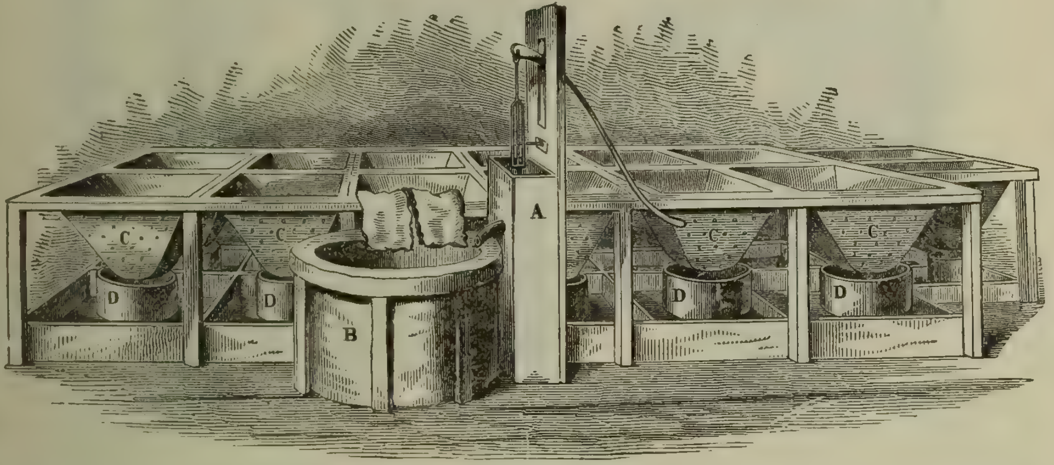


When the solution is sufficiently concentrated, it is drawn off by means of a pump, A (Fig. 4), into the cistern B, whence it is put into lead pans, similar to D, and allowed to crystallize. The supernatant liquor is then withdrawn for further concentration, the crystals dissolved, and the solution ladled into the filters, C C, which are lined with lead, the sides being pierced in numerous places. Each of these is supplied with a quantity of animal charcoal, which not only decolorises the fluid, but deprives it of its mechanical impurities. On percolating, it is received into the crystallizing pans, D D, in which it is allowed to stand until the crystals cease to form, or do so only very slowly. The mother liquor is again returned for evaporation. Two or three re-solutions and recrystallizations may be requisite to obtain an article of superior size and purity.

Solutions of citric acid are very liable to change during concentration; and the deepening colour and strongly empyreumatic acid smell indicate the loss which is sustained by conducting the evaporation in open steam pans. A great improvement was introduced in 1856 by Mr. E. A. Pontifex, who patented an apparatus for evaporating these solutions *in vacuo.* In this apparatus the temperature does not rise above 120° to 130° Fahr., and possesses the additional advantages that access of air is prevented, the time necessary for evaporation is diminished to one-eighth or one-tenth, and the strong ebullition keeps the liquid constantly in motion. In the ordinary system of evaporating by a steam coil, the movement in the dense solution is so slight, that a portion is left in contact with the steam pipes at a temperature approaching 220° Fahr. for a long time.

The apparatus consists of a leaden vessel, in which the acid liquors are evaporated, inclosed within an exhausted vessel, so that the pressure may be relieved from both the exterior and interior surfaces of the leaden vessel, or the exhaust vessel may be lined with lead, by dressing it down upon the outer vessel with some cement between them; or it may be made of an enamelled iron, which will not be affected by the acid, in which case the lining of lead is unnecessary. The overflow vessel contains a quantity of chalk, milk of lime, or some alkaline solution, through which the steam from the vacuum pan is conducted by means of a wide pipe terminating in a rose. Above the surface of the milk of lime is a priming plate, perforated with numerous holes, through which the steam can readily escape, but which will prevent the liquid being carried over mechanically by the violence of the agitation. The object of this vessel, which is furnished with suitable gauges and pipes for the supply of fresh or the discharge of spent solution, is to retain any volatile acids, such as acetic, butyric, or sulphurous, which would otherwise pass over and injure the apparatus. The overflow vessel would also collect any citric acid solution which might accidentally pass over from the evaporating vessel. The steam may be removed by the ordinary injection condenser; but the inventor prefers Pontifex's patent condenser, both on account of the economy of water required to work it, and also because the whole of the products of evaporation may be conveniently collected, and any loss of citric acid readily detected.

Fig. 4.



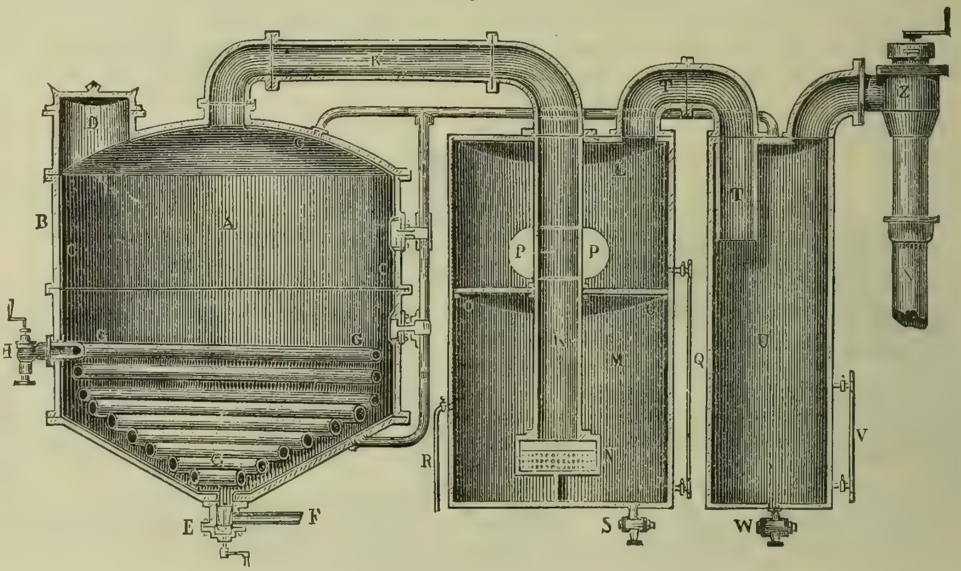
In order to prevent any leakage in the valves and cocks attached to the vacuum pan which might be caused by the action of the acid, the body of the valve is made of cast iron, lined with lead, and the valve face and disc are made of india-rubber. The spindle is protected from the action of the acid by a covering of lead.

Fig. 5 represents a sectional elevation of this apparatus; A is the vacuum pan, consisting of a cast-iron body, B, lined with lead, C C C; D is the manhole; and E, the valve at the bottom, for discharging the contents of the vacuum pan through the pipe, F. The acid solution, which is charged into the vacuum pan, is evaporated by means of the steam coil, G G G, into which steam is admitted by the valve, H; I I are pipes for exhausting the space between the leaden lining, C, and the outer cast-iron case, B; K K is the wide tube communicating with the overflow vessel, L M, and which is terminated in the rose, N; O O is the priming plate, which separates the upper and lower portions of the overflow vessel, and prevents the milk of lime from being carried over mechanically into the other portions of the apparatus; P P is the manhole; Q is a glass gauge, and R and S are cocks, the former to supply fresh absorbing solution, and the latter to draw off that which is spent. The upper portion of the overflow vessel, L, is connected by means of a tube, T T, with a safety vessel, U, likewise furnished with a gauge, V, and a discharge cock, W; X is the pipe communicating with the condenser and air-pump, and which can be cut off when required by means of the screw valve, Z.

Various modifications of the process of manufacture have been proposed, but as yet none of them have superseded that above described. KUHLMAN suggests saturating the hot lemon juice as far as possible with very finely-divided barium carbonate, and afterwards to complete the neutralization with barium hydrate or sulphide. The precipitate of barium citrate is then washed, and decomposed with the requisite quantity of sulphuric acid. The advantage of this method is, that the citric acid solution obtained in this way crystallizes more readily than when lime is employed as the precipitant. Sulphate of baryta is quite insoluble in solution of citric acid, whilst sulphate of lime is not, and the latter hinders the crystallization of the acid.

Dr. PRICE obtains a comparatively pure citrate of lime or baryta by neutralizing the lemon juice with an alkali, filtering from the mucilaginous precipitate, and then throwing down the citric acid as a citrate by means of a salt of lime or baryta. The citrate, after being washed, is decomposed in the usual way.

Fig. 5.



The juice may also be defecated to a considerable extent, according to Mr. ROW, by simply diluting it with water until it contains about 12 ounces of acid per gallon, and then filtering from the flocculent precipitate of mucilage thus thrown down. The citrate of lime precipitated from the dilute juice is comparatively pure.

In the manufacture of citric acid, the observation was made a long time since, that citrate of lime could not be preserved. It decomposes, and no longer yields citric acid—carbonic acid being a product of the decomposition, which remains behind in combination with the base; the nature of the change, however, was not known until PERSONNE examined the metamorphosis. He finds that it is a true fermentation, in which the citric acid splits up into acetic, butyric, and carbonic acids, with evolution of hydrogen.

When clarified lemon juice is saturated with lime, and a glass tube adapted to the vessel containing this mixture, it will be found that in the course of two days, at a temperature between 86° and 95° Fahr., gas is eliminated, and continues to be given off until the citrate is completely changed. Crude lemon juice undergoes this decomposition much more quickly than the clarified juice, but citric acid is still more speedily decomposed if mixed with citrate of lime and beer yeast.

The liquid in which the citrate of lime has disappeared gradually acquires the disagreeable odour of the butyric fermentation. It evolves a mixture of carbonic acid and hydrogen, in which the relative proportion of the one gas to the other, from the beginning to the end of the process, continually varies. The lime salts which are dissolved in the liquid, and which may be obtained by evaporation, yield argentic butyrate and acetate, if converted into the corresponding silver salts. The decomposition which takes place may be thus represented—

$$4C_6H_8O_7 + 2H_2O = 3C_2H_4O_2 + 2C_4H_8O_2 + 10CO_2 + 8H.$$

On account of the readiness with which moist citrate of lime is decomposed, it is impossible to prepare it on the spot from the lemon juice and then import it to this country for the manufacture of citric acid. M. PERRET has suggested, however, that the fresh lemon juice might be saturated with magnesia, which is abundant in many parts of Italy, and the insoluble citrate of magnesia thus obtained could readily be dried without undergoing decomposition, and in that state resists the action of a damp, hot atmosphere for a long time.

An improvement on this method, also devised by M. PERRET, is to convert the insoluble citrate of magnesia into a bibasic citrate. In order to effect this, one portion of the juice is precipitated with magnesia, and the insoluble tribasic citrate of magnesia thus formed is dissolved in another portion of hot lemon juice equal in quantity to that precipitated. After separating the insoluble matters by filtration or subsidence, the solution is concentrated in shallow evaporating pans until it attains a density of 23° Baumé. It is then allowed to cool, and in about twelve hours' time bibasic citrate of magnesia begins to come out. It crystallizes but slowly, requiring in some cases ten days before the whole of the salt is deposited.

In different states of purity citric acid is used extensively by calico-printers. In medicine, it is employed as a substitute for lemon juice, in the preparation of refrigerant drinks and effervescing draughts, and as an anti-scorbutic, anti-narcotic, and anti-alkaline.

As regards its physiological effects there are various opinions. ORFILA, for example, ranks it among the irritant poisons; whilst CHRISTISON and others gave drachm doses of it to cats, without observing that the animals suffered any inconvenience. Small quantities of it in water form an agreeable beverage, which allays thirst, diminishes preternatural heat, checks profuse perspiration, and promotes the secretion of urine.

ADULTERATION.—Citric acid and lemon juice are sometimes adulterated with tartaric acid, and to a very large extent. The best way to detect this fraud when the sophistication is considerable, is to dissolve a given weight of the acid in water, and to add gradually to it a solution of potassa, stirring briskly; crystals of acid potassium tartrate will fall or appear on the sides of the vessel, if any appreciable amount of the adulterant be present. If the quantity of tartaric acid be small, the solution of citric acid must be concentrated, and instead of employing potassa, chloride of potassium, or nitrate of potassium—all of which are serviceable when delicacy and accuracy are not required—use potassium acetate or citrate, which, being deliquescent, may be added at once, without being dissolved, to the suspected solution.

When citric acid attracts moisture on exposure to the air, it is a proof that it retains a small portion of the sulphuric acid used in its preparation, which is very readily detected by dissolving in water, adding hydrochloric acid and chloride of barium. If a white precipitate or milkiness is produced, sulphuric acid is present. Re-crystallizing several times will at once purify it. Tartaric and sulphuric acid are often mixed with the raw lemon juice; and it is a fact, however unpleasant to mention, that hundreds of ships sail from Liverpool and London with an article sophisticated with *oil of vitriol*, &c. Mr. THIN remarks that this adulterated article, on account of its intense acidity, meets with more approval from the common palate than the agreeable acerbity of the genuine juice.

COAL TAR DISTILLATION.—The constituents of the tar obtained by the destructive distillation of coal vary much, both in their nature and their relative proportions, not only with the nature of the mineral distilled, but with the average temperature employed in the distillation. As a rule, the lower the temperature the larger the yield of liquid and solid products, and the less the amount of gas formed, and the higher its illuminating power. Towards the end of the gas-making operation, when the contents of the retorts are heated to a maximum, little but hydrogen is evolved; but in the earlier stages there are produced hydrocarbons and oxidized matters, some permanent gases, some readily combustible vapours, some solids at the ordinary temperature, together with sulphurized and nitrogenous bodies. For the description of the products obtained by the distillation of coal and analogous substances at low temperatures, *vide* the articles PARAFFIN, PARAFFIN OIL, in Vol. II., the present article merely referring to that variety of tar which is obtained during the distillation of gas coal for illuminating purposes.

According to the kind of coal used, and the way in which the gas-making is conducted, a tar is obtained differing somewhat in properties. Thus, cannel coal distilled at low temperatures gives a tar lighter than water, and not readily drying in the air (LETHEBY); ordinary gas coal, as distilled in the provinces, gives a tar heavier than water and readily drying in the air; whilst London coal tar, being produced at a higher temperature still, is still heavier; moreover, it is less in quantity, and is deficient in the more volatile constituents, whilst it contains much naphthalene.

The main constituents of coal tar may be thus classified:—

(A) HYDROCARBONS.

1. Of the Marsh Gas Family:—

Marsh gas,	CH_4	Existing as gases dissolved in the tar.
Higher homologues,	?	
Pentane,	C_5H_{12}	More than one isomeride.
Hexane,	C_6H_{14}	"
Heptane,	C_7H_{16}	"
Octane,	C_8H_{18}	"
Decane,	$C_{10}H_{22}$	"

And probably others constituting solid paraffin.

2. Of the Olefine Series:—

Olefiant gas,	C_2H_4	Existing as gases dissolved in tar.
Propylene, (?)	C_3H_6	
Tetrylene, (?)	C_4H_8	
Amylene,	C_5H_{10}	
Hexylene,	C_6H_{12}	
Heptylene,	C_7H_{14}	

And probably others.

3. Of the Benzene Family :—

Benzene, ...C_6H_6
Toluene,...........C_7H_8
Xylene,............C_8H_{10} } Possibly other isomerides.
Isoxylene, ...C_8H_{10} }
Pseudocumene, ...C_9H_{12} } "
Mesitylene, ...C_9H_{12} }
Tetramethyl benzene, ? .... $C_{10}H_{14}$ "

4. More highly Carbonized Hydrocarbons :—

Styrolene, ? ....C_8H_8
Naphthalene,..........$C_{10}H_8$
Naphthalene hydride, (?) $C_{10}H_{10}$
Acenaphthalene, ...$C_{12}H_{10}$
Anthracene, ...$C_{14}H_{10}$
Phenanthrene, ...$C_{14}H_{10}$
Pyrene, ...$C_{16}H_{10}$
Chrysene, ...$C_{18}H_{12}$
Chrysodene, ... ?
Bitumene, ... ?
Benzerythrene, ... ?
And others less fully investigated.

(B) Substances containing Oxygen.

Water, ...H_2O
Wood spirit, ? ....CH_4O
Acetic acid, ...$C_2H_4O_2$
Compound ethers,...... Various.
Phenol (carbolic acid), ..C_6H_6O
*Creosol, ...C_7H_8O { More than one isomeride (?)
Higher homologues.
Besolic acid, ... ?
Brunolic acid, ... ?

(C) Sulphurized Substances.

Ammonium sulphide, or sulphydrate.
" sulphocyanide,....... .....$NH_4.CNS$
Carbon disulphide,......................CS_2
And probably other bodies.

(D) Nitrogenous Bodies.

(1.) Ammonia series :—

Ammonia..............NH_3
Methylamine, (?) ..NCH_5
Higher homologues,.. . ?

(2.) Pyridine bases :—

Pyridine, ...C_5H_5N
Picoline,..............C_6H_7N
Lutidine, ...C_7H_9N
Collidine, ...$C_8H_{11}N$
Parvoline, ...$C_9H_{13}N$
Coridine, ...$C_{10}H_{15}N$
Rubidine, ...$C_{11}H_{17}N$
Viridine,.. ....$C_{12}H_{19}N$

(3.) Leukoline bases :—
Leukoline,.............C_9H_7N
Lepidine,..............$C_{10}H_9N$
Cryptidine,............$C_{11}H_{11}N$

(4.) Pyrrol,. ....C_4H_5N

(5.) Aniline bases :—

Aniline, ...C_6H_7N
Toluidine, (?).........C_7H_9N
Higher homologues, ... ?

(6.) Cyanogen compounds.

(7.) Other nitrogenous constituents :—

Acridine,..............$C_{12}H_9N$ (or $C_{24}H_{18}N_2$)
Carbazol, ...$C_{12}H_9N$

(E) Non-volatile Matters, constituting Pitch.

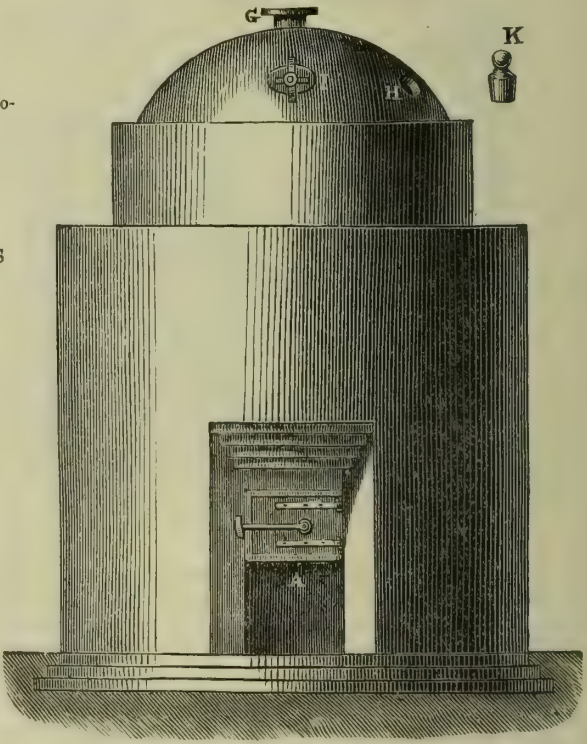
Many of the substances in the above list do not exist as such in the tar, but are formed during the further distillations to which the tar is subjected.

Of these numerous bodies only a few are extracted for commercial purposes, those mostly in demand being :—

Ammonia,
Benzene and its homologues,
Carbolic acid,
Naphthalene,
Anthracene,
Pitch.

The ammonia is mainly present dissolved in the aqueous liquor which is formed during the distillation of coal, and which is only incompletely separated by mechanical means from the tar; for the methods employed in the utilization of this liquor *vide* article Ammonia. The crude ammonia liquor often contains inflammable gases dissolved, which burn without smoke.

Fig. 1.—Scale 1 inch to 4 feet.



The different constituents of the coal tar are separated by distillation, the various fractions of distillate obtained being subjected to further purifying processes. Owing to the magnitude to which the manufacture of coal tar products has now attained, the first rough distillation of coal tar has come to constitute a distinct trade of itself, the various crude products manufactured and sold by the coal tar distiller being usually refined by the purchaser: the processes adopted in these refining operations are described under the headings Benzol, Carbolic Acid (Disinfectants), and further on under *Anthracene*, &c. At present we confine ourselves to the preparation of the crude substances.

This preparation, as usually carried on in the vicinity of London, may be thus generally described:—The coal tar is allowed to stand in large tanks, so that as much ammoniacal liquor as possible shall separate mechanically by rising to the surface; the heavier tar is then pumped off from the bottom of the tank into a still, where it is heated. Permanent gases, water charged with ammonium sulphide, and the more volatile portions of the tar make their appearance at first, and are collected apart as *ammoniacal liquor* and *first light oils.* After a short time, the stream of liquids running from the condenser slackens and almost ceases; this is termed "the break," and lasts for a short time until the temperature of the still rises somewhat: the stream then recommences, what escapes from the condenser being collected apart as *second light oils.* When the density of the distillate becomes such that the liquid sinks in water, the collecting recipient is again changed, the oils now running being known as *creosote oils;* the first portions of these contain much naphthalene, which without due care is apt to block up the condenser. Later on, the naphthalene present lessens and is kept wholly in solution by the liquid oils; by and bye the distillate begins again to acquire the property of thickening on cooling; the fractions collected after this phenomenon appears is known as *anthracene oil.* When the distillate is semi-solid on cooling (about the consistence of butter), the operation is concluded; on an average, about two-thirds (67 per cent.) of the tar is then left in the still in the form of pitch.

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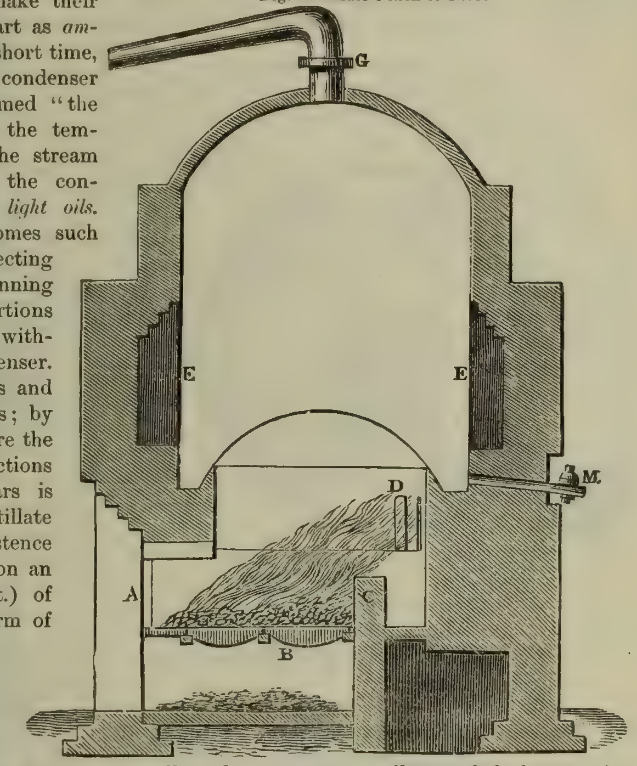
* Creosote proper has the formula $C_8H_{10}O_2$, and is wholly different from the creosol or cresylic alcohol of coal tar.

Before the discovery of the process of manufacture of alizarin from anthracene, the last portions of distillate were useful for little but the production of lubricating materials; the distillation was then carried on to a point dependent on the nature of the pitch required (hard or soft). At the present day it is an object to carry the distillation as far as possible, so as to obtain the maximum yield of anthracene; if, however, it is required to sell the pitch, the distillation must not be pushed too far, otherwise the pitch becomes "coked" and worthless as pitch. When, however, it is requisite that this should be done, it is necessary to perform the coking distillation in a separate vessel, so as to diminish the difficulty and expense of extracting the residual coke from the still: special stills have been constructed for this purpose.

In some works in Scotland the tar is first heated in a still provided with a steam jacket, or steam is blown through the tar till the more volatile products are expelled. All that can be got off by steam heat is then sold for the purpose of extracting benzol (*q. v.*); the residue, known as "boiled tar," is then run into another still heated by a free fire and distilled; the second light oils and subsequent fractions being collected as above. These light oils are largely used for burning purposes. On the Continent, too, the tar is frequently heated in a vessel provided with a steam jacket, so as to cause the separation of watery liquor (*vide infra*); the dehydrated tar is then run off and distilled over a free fire.

The first and second light oils are worked up for benzol, solvent naphtha, and carbolic acid. From the creosote oils, more particularly the lower half, naphthalene separates in quantity on standing; this is collected on coarse woollen sackcloth, or wire gauge filters, and squeezed by hydraulic or other pressure, and sold as crude naphthalene.

Fig. 2.—Scale 1 inch to 4 feet.



The anthracene is separated from the anthracene oils in just the same way, and is rarely subjected to any purifying process by the tar distiller himself. The modes of purifying this crude product, its valuation, &c., will be described below.

The following diagrams and description of the usual disposition of a London tar still, and its appliances, with the annexed description of the usual method of working it, were obligingly forwarded to the writer by Mr. A. J. Dickinson.

Fig. 1, front elevation; Fig. 2, section from front to back; Fig. 3, plan; Fig. 4, plan of top of still. A, furnace door; B B, fire-bars; C, bridge; D D D D, openings into flue; E E, circular flue, with stop at L; F, exit to chimney; G, still head; H, charging hole closed with conical plug, K; I, manhole; K, plug for closing charging hole; L, stop in circular flue; M, pitch-cock.

A still holding about 1200 gallons is to be preferred, as this charge can be worked off in ten to twelve hours, thereby avoiding the necessity of night-work; larger sizes, however, are frequently used. The relative disposition of the plant in a tar work of course depends much on the nature of the ground and other circumstances, but, as a rule, the still should be placed as near the tar tank as possible; and the connecting pipe between the still head and the condensing worm should be placed on the opposite side to the furnace door, so that in case of a pipe breaking there might be time to damp out the fire before the issuing vapours reach the furnace. Similarly the cock for withdrawing the hot liquid pitch is placed on the side opposite to the furnace, to avoid the chance of firing the vapours evolved as the hot mass flows out to the pitch tank.

Fig. 3.—Scale 1 inch to 4 feet.

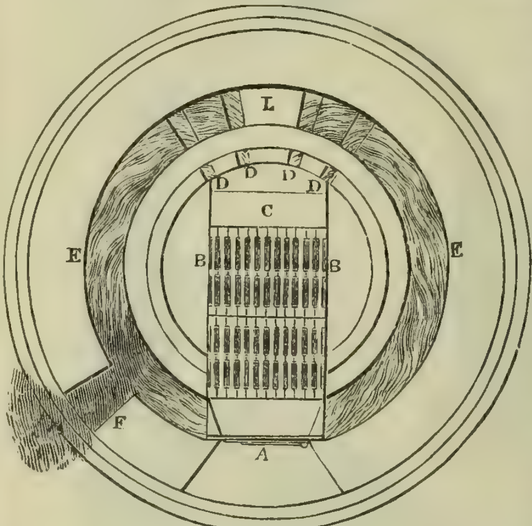
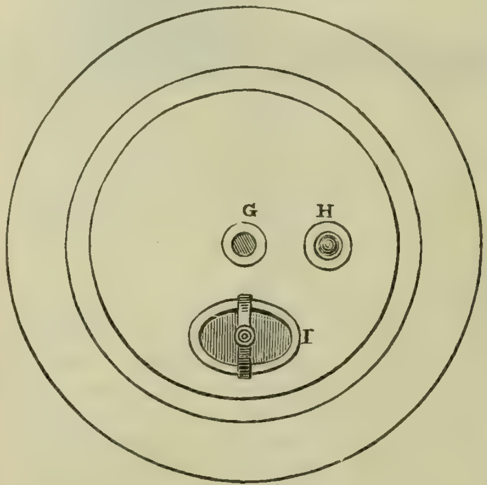


Fig. 4.—Scale 1 inch to 4 feet.



The condensing worm is usually a 4-inch socket pipe in 6 and 9 feet lengths with elbows, arranged in a rectangular tank; about 140 feet total length is usually sufficient for this size of still, but a thoroughly efficient condensing arrangement is most essential.

The following is a description of a day's working. About 6 a.m. the still is charged with about 1200 gallons of tar, and the fire is lighted; in about an hour the tar begins to rise in the still, and the fire requires careful watching, being slacked and increased as required, until the distillation commences (which it does about two hours after the fire is lighted).

The first portion of distillate consists of gases, ammonia water, and first light oils (naphtha); when about 60 to 70 gallons have passed over (containing about 20 to 25 of naphtha and the rest water), the "break" occurs (called so from the fact that the still almost ceases working); with the above mentioned size of still this usually lasts for an hour, or an hour and an half, during which time little but water passes over, the generation of steam being accompanied by a peculiar noise, so that the still is said to be "on the rattles" during this period. When the temperature has increased sufficiently, the still "comes off the rattles," and throws off about 20 gallons of oil lighter than water. The point at which the distillate begins to be heavier than water is readily found by simply collecting some of the distillate, and noticing whether the oil or the aqueous portion rises to the top. As soon as the oil sinks to the bottom of the water, the shoots are changed, and the still is said to be "on the oil:" this point can also be told by the colour of the oils, the second light oil looking whiter, and having a thread of reddish water running off along with it. About 300 gallons more are then distilled off, which requires about three hours; of this the first portion chiefly consists of naphthalene, and at this point particular attention must be paid to prevent blocking up of the worm. When about 150 gallons have run off the nature of the products changes, and the still is said to be "on the soft oil," the naphthalene being wholly soluble in the liquid oils then running; the oils at this point are called "sharp soft oils." After this the oil begins to thicken on cooling; the approach to this point is tested by simply catching a little of the oil on a piece of iron; the still is then said to be "on the anthracene oil"—about 50 gallons of the 300 consist of this. When the oil sets to about the consistence of butter on the iron, the fire is withdrawn. This stage is reached about 5 p.m.; the residue in the still then consists of coal-tar pitch, weighing about 4 tons.

The average produce from 1200 gallons of tar (about 6 tons) is—

Ammoniacal liquor,	about 50 gals.	= about 4 p.c. by weight.
First light oils,......	" 20 "	" 1·5 "
Second light oils,...	" 20 "	" 1·5 "
Creosote oils.........	" 250 "	" 22 "
Anthracene oils,....	" 50 "	" 4 "
Pitch,................	" 4 tons	" 67 "
		100

The above quantities fluctuate somewhat according to the quality of the tar.

From the 50 gallons of anthracene oil about 1 cwt. of crude anthracene (at 30 per cent.) is obtained by standing and pressure; the liquid oils, from which the solid anthracene separates, serve for the preparation of lubricating grease, &c.

Lunge describes the following form of still as frequently used in Great Britain (Figs. 5 and 6):—

Fig. 5.

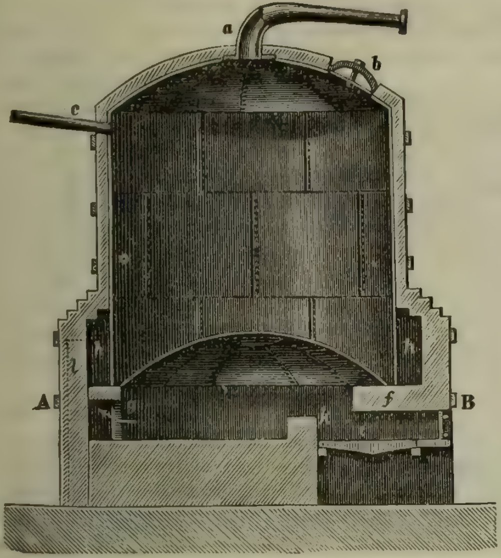
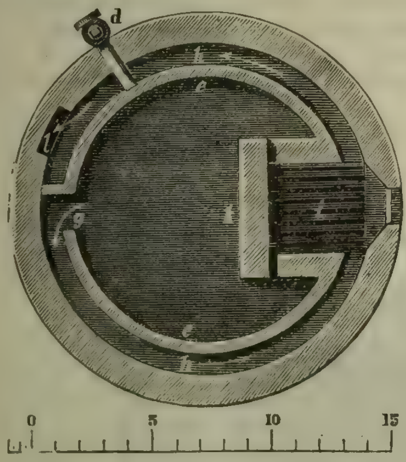


Fig. 6.



The still is constructed of ¾-inch boiler-plates, well rivetted together—*a*, still head, the orifice in the still is 12 inches diameter, the bent neck tapering down to 4 inches clear; *b*, manhole made tight with clay (india-rubber washers cannot be used); *c*, tube for conveying tar to still from tar tank; *d*, exit-pipe for liquid pitch, *e e*, circular sustaining wall on which the still rests; *f*, crown of arch over fire-place, preventing over heating of still in that part; *g*, upcast flue leading to annular flue, *h*; *h h*, annular flue; *i*, fireplace, 4 feet square, *k*, fire-bridge, 18 inches high; *l*, flue to chimney; A B, level at which the horizontal section, Fig. 6, is made.

Other forms of still are, however, frequently used, especially on the Continent. Bolley divides tar stills generally into four kinds ("Technologie," B. V., 2, Braunschweig, 1870).

(A) Cylindrical wrought-iron stills (the diameter of which exceeds the height); with flat or arched bottoms (Fig. 7).

(B) Cast-iron cauldrons of almost globular shape (Fig. 8).

(C) Vertical cylinders of boiler-plate, of greater height than diameter; bottoms concave, roofs convex (Figs. 5 and 6).

(D) Waggon-boilers of D-shaped sections; or horizontal cylindrical boilers (Figs. 9 and 10).

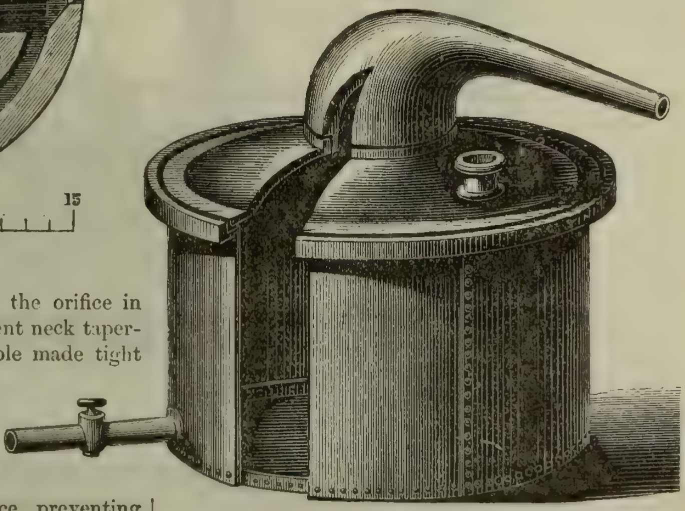
Figs. 9 and 10—A, still protected from direct action of fire by brick arch; *s s s*, flue making 2½ turns round still; *p*, still head; *q*, manhole; *u*, exit-pipe for hot pitch.

Fig. 11 indicates a convenient form of cock for drawing off the hot liquid pitch.

Fig. 12 indicates a form of condenser recommended by Bolley. The upper zig-zags are made of cast-iron pipes, 3 inches in diameter, to diminish the risk of plugging up with solid hydrocarbons; the lower ones are only 1½ inch diameter. At each end of each pipe is a plug fixed tight by a frame and screw, by means of which obstructions can be readily cleared away should they occur, the plug being removed and a cleansing-rod thrust into the pipe; to facilitate this operation the tank in which the condenser is placed is made of smaller dimensions, so that the H-shaped joints project outside its ends.

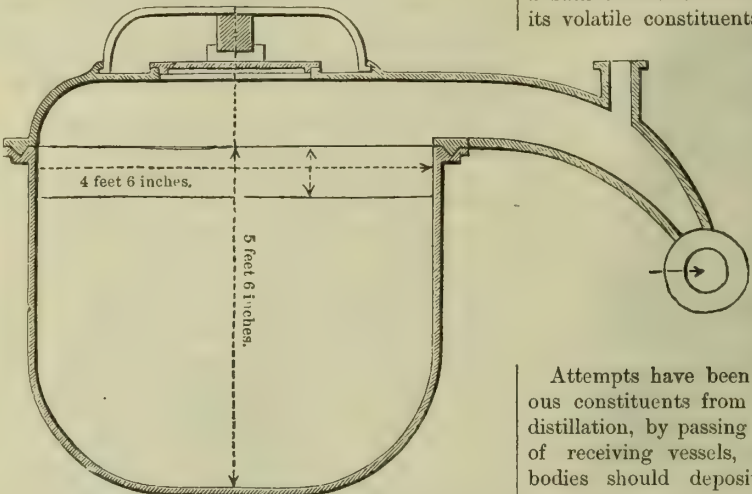
Some continental distillers employ more than one worm-shaped condenser, differing for each kind of distillate. The first (used for the lightest oils) is made of a much narrower tube than the one employed for the heavy oils, the greater width in the latter case being adopted to diminish the risk of plugging up the condenser by deposition of solid hydrocarbons, &c.; for the same reason, the water round the first condenser is kept as cool as possible by means of a continuous supply of cold water to the condensing tank, whilst that round the condenser for heavy oils is

Fig 7.



kept at a temperature of 60° to 70° C. The same result is, however, more conveniently and cheaply attained by employing only one sufficiently wide condensing worm, and regulating the supply of water to the condensing tank, so that it is as cold as possible at the commencement of the distillation when the light oils pass over, but becomes warmed up as the heavier oils begin to distil.

Fig. 8.

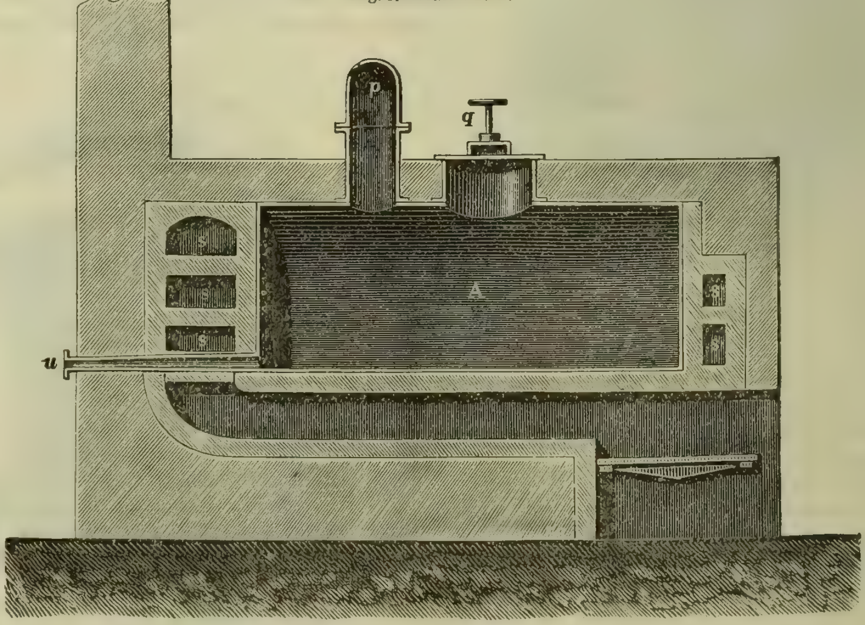


Other distillers pass a jet of steam into the still to facilitate the regular disengagement of vapours. Attempts have also been made to make the distillation a continuous process, a stream of tar being made to enter at one end of the arrangement, pitch issuing at the other end. For this purpose Mallet employs a bath of molten lead over which the tar flows, its volatile constituents being expelled during its onward progress, and being separately collected by fixing partitions in the distilling vessel in such a way that the tar can freely flow from one end of the lead-bath to the other, whilst the vapours evolved in different parts kept are separate the one from the other. The economy of this arrangement is, according to Knabe, doubtful.

Attempts have been made to separate the various constituents from one another during the first distillation, by passing the vapours through a series of receiving vessels, so that the less volatile bodies should deposit in the first condenser, and the most volatile in the last; but the results have not been satisfactory, although processes of this kind have given good results when the first crude distillates are redistilled. (*Vide* Benzol.)

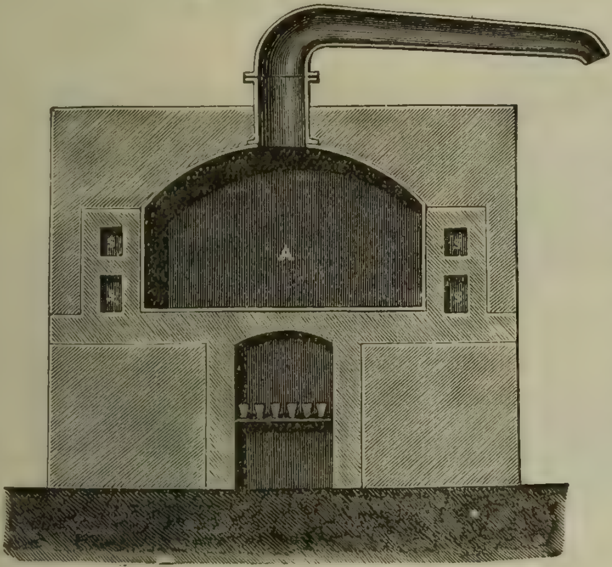
The method for the first rough fractionation of coal tar practised on the Continent differs from that above described (which represents the process usually employed in England) in several respects. According to this method the separation of the last traces of ammonia liquor from the tar is effected by heating the tar for 20 to 30 hours to from 80 to 90° C., in a large boiler furnished with a condenser, so as to retain any light oils volatilized during the heating. The vessel is sometimes heated by an ordinary furnace, but on account of the great danger from accidental

Fig. 9.—Scale 1-20th.



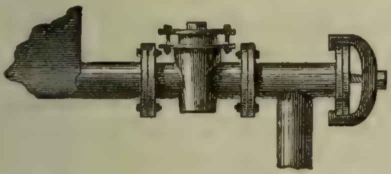
leakage, a steam-jacket or a steam-worm is usually employed.

Fig. 10.—Scale 1 20th.



The tar *floats on the top** of the ammoniacal liquor, which is drawn off by a cock in the lowest part of the boiler, a little of the lower layer of tar (more or less mixed with water) being also drawn off with it.

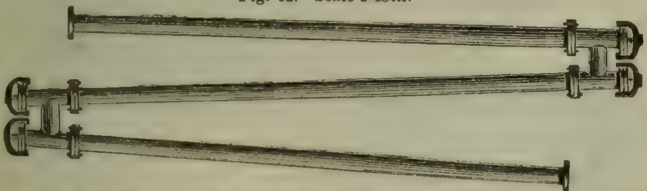
Fig 11.—Scale 1-24th.



The tar thus freed from water is then pumped, while yet hot, into the still.

This process of separation, or one the same in principle, is described by Bolley as extensively used in Germany.

Fig. 12.—Scale 1-48th.



The still recommended as most convenient is a cylindrical one mounted horizontally in brickwork, so that the direct fire does *not* play upon its bottom, the heat being communicated by flues circulating round the lower portion, the highest of these being at no higher an elevation than the level of the residual pitch when the distillation is finished, otherwise the still and its contents are apt to be burnt. In the stills usually employed in England the fire plays *directly upon the bottom.* The flues are provided with dampers to regulate the draught and hence the temperature, and a dome is fixed on the top of the boiler (*still head*), from which issues the tube passing to the condenser (or condensers, if more than one be used). A gutter runs round this dome internally, so that any liquid condensed in the upper portions may run to the condensing worm, and not drop back into the still, as this might at times cause bubbling up and foaming of the contents. The ball of a thermometer is inserted into the dome through an orifice for the purpose, so that the temperature of the thermometer can be read off (the steam being still outside).

The fractions collected are regulated by the thermometer thus:—†

	Density.	Temperature of distillation in degrees C.
First fraction or light oils, ...	0·78 to 0·85.....	30° to 140°
Second fraction or medium oils,	0·83 to 0·89	150° to 210°
Third fraction or heavy oils, ...	0·92 to 0·93 (?). .	220° to 350°

The table (on next page) represents a sketch of the treatments to which these various fractions are further subjected in order to obtain from them purified hydrocarbons, suitable for the manufacture of aniline, for dissolving india-rubber, for the manufacture of lubricating oils, &c., according to the nature of the product; the acid and alkaline liquors obtained by the wet treatments being put aside for the extraction of carbolic acid, &c.

It is noticeable that in the process of tar distilling thus described, the anthracene present in the tar is either not extracted at all or only imperfectly. During the last two or three years this substance has acquired a vastly increased importance, so that the efforts of the tar distiller are now directed towards obtaining as large a yield of this hydrocarbon as is consistent with the other objects in view; this table, therefore can only be taken as indicating the treatment of the lower boiling oils obtainable from coal tar (*vide* Benzol); the pitch produced being of a considerably softer character than that usually prepared at the present time, when the distillation is carried on as far as is practicable without rendering the pitch unsaleable.

---

* When cold, ordinary tar is heavier than ammoniacal liquor, which floats to the top. In Scotland the tar is often heated in a steam-jacketted still, whereby the first light oils are distilled off. The residue is then run off to another still heated by a free fire, and the distillation finished therein.

† This mode of regulation is not adopted in England, the fractions being distinguished from one another as above described, viz. :—That coming over before "the break" (first light oils); that coming over after "the break," and having a density not greater than that of water (second light oils); that having a density greater than that of water (creosote and anthracene oils = heavy oils). The so-called "heavy oils" of the Continent in no way correspond in sp. grav. to the English heavy oils; they answer more nearly to the English second light oils in this respect.

FIRST DISTILLATION—

COAL.

GAS. TAR. COKE.

SECOND DISTILLATION—

TAR.

CRUDE LIGHT OILS (30°—150° C.). CRUDE MEDIUM OILS (140°-200° C.). CRUDE HEAVY OILS (200°-350° C.). PITCH.

THIRD DISTILLATION.

CRUDE LIGHT OILS.	CRUDE MEDIUM OILS.
Fraction No. 1, Naphtha, passes below 140° C. Fraction No. 2, passing above 140° C., added to the medium oils.	Fraction No 1, passing below 130° C., added to naphtha. Fraction No. 2, rectified medium oil. Fraction No. 3, passing above 200° C., added to heavy oils.

TREATMENT BY THE WET PROCESS.

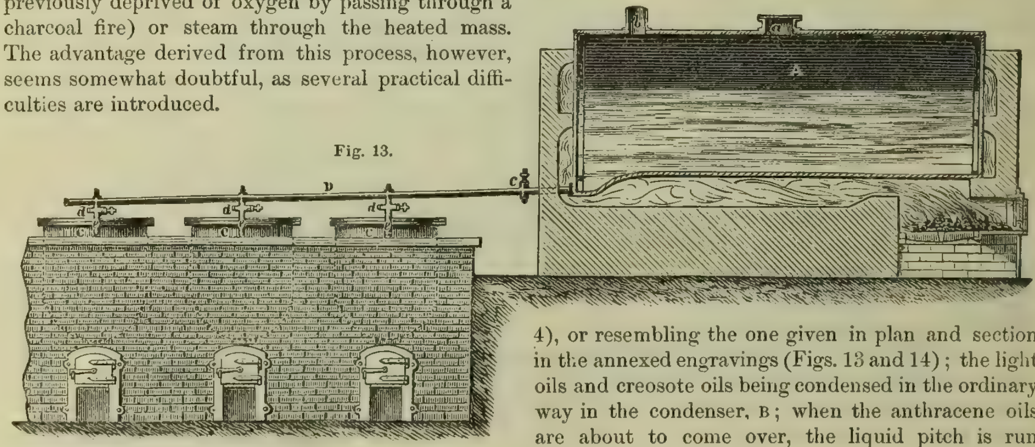
RECTIFIED LIGHT OILS OR NAPHTHA (39°-140° C.).	RECTIFIED MEDIUM OILS (140°-200°C.).	CRUDE HEAVY OILS.
1. Washing with pure water. 2. " sulphuric acid. 2. " water. 1. " soda. 2. " water.	1. Washing with pure water. 2. " sulphuric acid. 2. " pure water. 1. " soda. 2. " water.	1. Washing with pure water. 2. " hydrochloric acid. 1. " pure water. 1. " soda. 2. " pure water.

FOURTH DISTILLATION.

NAPHTHA.	RECTIFIED AND PURIFIED MEDIUM OILS.	PURIFIED HEAVY OILS.
Fraction No. 1, passing between 39° and 80° C. Fraction No. 2, passing between 80° and 115° C.—Benzol. Fraction No. 3, passing between 115° and 150° C. Fraction No. 4, passing above 150°.	Fraction No. 1, passing between 140° and 190° C. Fraction No. 2, passing above 190° C., added to the heavy oils.	Fraction No. 1, 215°-230° C. Fraction No. 2, 230°-290° C. Fraction No. 3, 300°-340° C.

Several patents have been taken out of late years for the production of the maximum possible quantity of anthracene by completely coking the pitch; in some of these, such as those of KOPP, and BRUMER, and GUTZLOW, the evolution of vapours from the heated pitch is facilitated by passing air (preferably previously deprived of oxygen by passing through a charcoal fire) or steam through the heated mass. The advantage derived from this process, however, seems somewhat doubtful, as several practical difficulties are introduced.

Fig. 13.

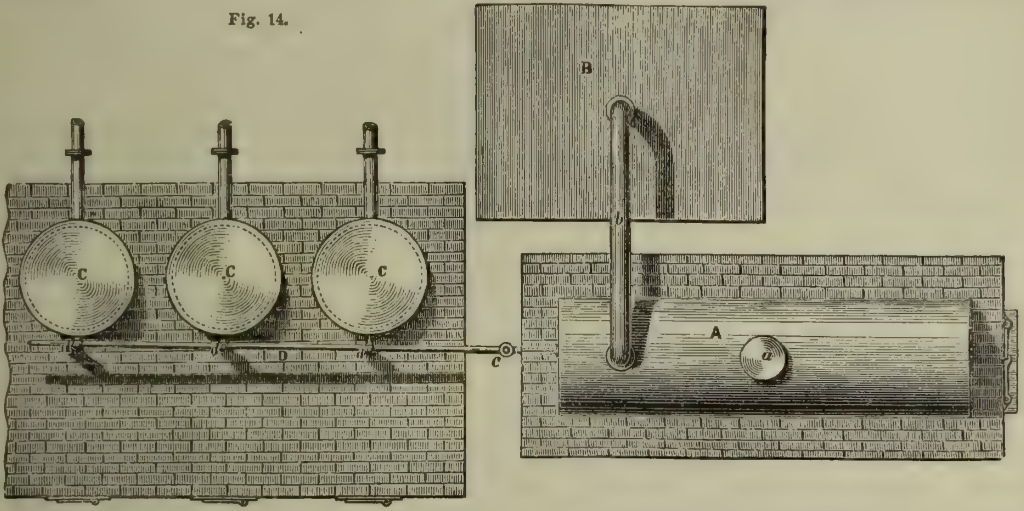


The following distilling arrangement is proposed by FENNER and VERSMANN for the distillation of tar, the more immediate object of the apparatus being to obtain the largest possible yield of anthracene, the pitch being *entirely coked* during the process. Coking the pitch cannot possibly be effected in the form of English still above described, the loss of time and cost of labour in chipping out the solid coke, and the damage thereby done to the still, being too great.

The tar is distilled in a wrought-iron still or boiler similar to the one above described (Figs. 1, 2, 3, and 4), or resembling the one given in plan and section in the annexed engravings (Figs. 13 and 14); the light oils and creosote oils being condensed in the ordinary way in the condenser, B; when the anthracene oils are about to come over, the liquid pitch is run (whilst still hot) into a series of vessels, C C C, in which the coking is effected.

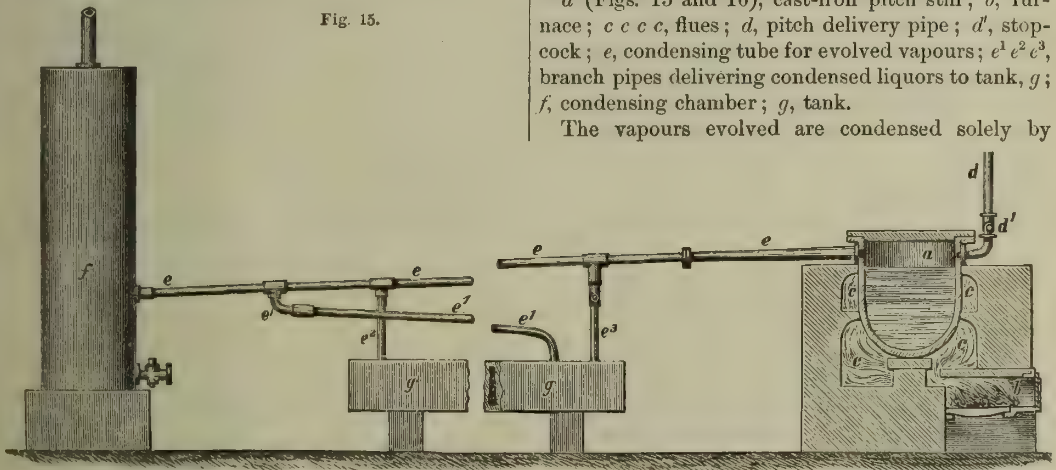
A (Figs. 13 and 14), still in which the tar is first distilled; B, tank, with condensing worm for light oils and creosote oils; *a*, manhole, *b*, orifice with which the condensing worm is connected; *c*, tap whereby liquid pitch is run off into main, D; D, pitch main; C C C, cast-iron pitch stills; *d d d*, taps whereby pitch is run into the stills; *e e e*, delivery pipes for liquid pitch.

Fig. 14.



These vessels (*a*, Figs. 15 and 16), are made of cast iron, and are about 4 feet diameter, and 4 feet 8 inches deep (internal measurement); it is alleged that, when set in the way indicated in the diagram, they will last five or six years when worked so as to distil off one charge of 1½ to 2 tons of pitch every three days, one day being occupied in the distillation, and two more in the cooling, emptying, and recharging. A production of 10 tons of pitch per day therefore requires three sets of six cast-iron pots each for the coking operation.

Fig. 15.



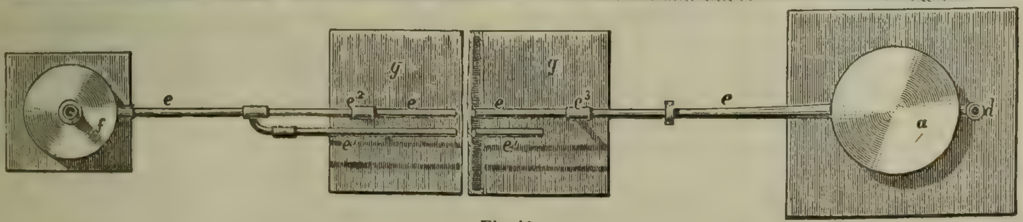


Fig. 16.

a (Figs. 15 and 16), cast-iron pitch still; *b*, furnace; *c c c c*, flues; *d*, pitch delivery pipe; *d'*, stopcock; *e*, condensing tube for evolved vapours; $e^1\, e^2\, e^3$, branch pipes delivering condensed liquors to tank, *g*; *f*, condensing chamber; *g*, tank.

The vapours evolved are condensed solely by atmospheric cooling, partly in the tube, *e*, partly in the condensing chamber, *f*. The evolution of vapour is greatly facilitated by creating a partial vacuum in the pot, *a*, by means of an exhauster or blower attached to the exit of the chamber, *f*, but no advantage is derived by blowing either hot air or steam through the pitch. Towards the latter part of the distillation the branch tubes, $e^1\, e^2\, e^3$, are successively opened, so as to provide as short and ready a passage as possible for the escape of the condensed bodies into the tank, *g*. This is essential, otherwise the vapour-delivery pipe, *c*, is apt to become blocked by the separation of solid matter.

The distillate at 600° to 700° Fahr. (315° to 370° C.) is, according to Fenner and Versmann, very rich in anthracene, but little naphthalene or chrysene being therein present; between 500° and 600° Fahr. (260° and 315° C.) the naphthalene is in excess; above 700° Fahr. (370° C.) anthracene is less abundant, chrysene and other bodies of higher boiling point than anthracene being the main constituents of the distillate. On standing, these distillates deposit solid matter, from which rough anthracene is separated by filtration, washing with lighter oils, &c., and pressing.

The cast-iron pots and other plant shown in Figs. 2 and 3 may also be used for the distillation of pitch, purchased as such for the purpose of extraction of anthracene from it. For this purpose the pitch is broken up into small lumps, and preferably mixed with oils arising from a previous distillation, or with dry absorbent carbonaceous matter. The object of this is to prevent frothing, and consequent blocking up of the vapour-delivery tubes on first heating, owing to the presence of moisture in the pitch. The patentees state that, on an average, 2 per cent. of anthracene is thus obtainable from ordinary pitch. As ordinary coal tar yields about 0·5 per cent. of rough anthracene, and 67 per cent. of pitch (this latter corresponding to 1·33 anthracene per 100 of original tar), it results that the production of anthracene is nearly quadrupled when the tar is coked—*i.e.*, 1·85 per cent. altogether is obtained instead of 0·5 per cent., the correctness of the above statement being assumed. It must, however, be noticed, that alizarin makers have recently found that "pitch anthracene" prepared by Fenner and Versmann's process, or by some analogous method, is not well suited for the manufacture of colour on account of the practical inconvenience occasioned by the large admixture with chrysene, &c.; and hence that this article is almost unsaleable in consequence. Several lawsuits have sprung out of this circumstance. The coke which is left in the pots is hard and dense, and being free from sulphur, is very valuable for many metallurgical processes. The oil from which the anthracene is separated is a good lubricator.

Kopp recommends the use of stills of moderate size for the distillation of soft pitch, the expulsion of the vapour towards the end being facilitated by the injection of steam or air into the still, or preferably of a mixture of nitrogen and carbon oxide, produced by forcing air through a red-hot mass of coke.

The quantities of valuable commercial products obtainable from coal tar vary much according to the nature of the original coal, the mode of distillation employed, &c. It is noticeable that, as a rule, when tar is rich in anthracene it is poor in toluene and higher homologues (although containing much benzene), and *vice versa;* and it has hence been argued that anthracene is at least partially formed at the expense of these hydrocarbons. In point of fact Berthelot has shown that when toluene vapour is passed through a red-hot tube much benzene and anthracene are formed; the same holds for the mixture of hydrocarbons known as coal-tar xylol; whilst coal-tar cumol (the next higher homologous mixture of isomerides) yields, under the same conditions, little benzene and anthracene, but much toluene. It is probable that the anthracene obtained by the distillation up to coking of pitch does not pre-exist as such in the pitch, but is formed during the heating operation (Versmann). As a rule, the more hydrogeneous the coal, the larger the yield of tar from it.

The following estimates have been made as to the average yield of various constituents and products from coal tar.

Crace-Calvert.—100 parts of tar of the undermentioned classes contains the following ingredients:—

	Source of Tar.			
	Boghead coal.	Cannel coal.	Newcastle coal.	Stafford-shire coal.
Benzol,	12	9	2	5
Carbolic acid,	3	14	5	9
Heavy hydrocarbons,	30	40	12	35
Paraffin,	41	—	—	—
Naphthalene,	—	15	58	22
Dry tar,	14	22	23	29
	100	100	100	100

Perkin.—100 lbs. of coal yield—

	Lbs.	Ozs.		Parts by weight.
Tar,	10	12	=	100
Coal-tar naphtha,	—	8½	=	5
Benzol,	—	2¾	=	1·6

Girard and De Laire.—French tars—

	Parts.
Tar,	100
Liquid pitch,	75—80
"Fat" pitch (soft pitch),	60—70
Dry pitch (hard pitch),	50—60

Versmann.—Average English tars—

	Parts.
Coal,	1000
Tar,	45
Pitch,	30

Tar,	100
Pitch,	67
Benzol,	1½
Anthracene (of from 30 to 60 per cent.),	1·85*
Anthracene (about),	0·5 †

Letheby.—English tars:—1 ton of gas coal as distilled in London gives about 9 to 10 gallons of tar: 1 ton of coal as distilled in the provinces gives about 15 gallons of tar: 1000 gallons of London tar yield:—

	Gallons.		Average. Gallons.
Ammoniacal liquor,	20 to 28	..	24
Crude naphtha (first light oils),	12 to 20	..	16
Second light oils,	4·8 to 14	..	12
Creosote oils,	275 to 276	..	288
	Tons.		Tons.
Pitch,	3·2 to 4	..	3·6

After purification by the process described in the article **Benzol** these light oils yield (per 1000 gallons of tar):—

---

* The pitch being wholly coked.

† The pitch not being coked.

	Gallons.	
40 per cent. benzol,	3·44	= 6·84 at 90 per cent.
90 per cent. benzol,	5·31	
Solvent naphtha	4·18	
Last runnings,	1·2	
Total dead oils,	301·87	

R. F. Smith.—Average English tar—1 ton of tar (sp. gr. 1·145) = 195·7 gallons, yields:—

	Gallons.		By vo'ume. Per cent.
Ammonia water,	3	=	1·5
First runnings,	6	=	2·1
Light oils.	21½	=	10·9
Creosote oils,	66	=	33·7
	Cwts.		By weight.
Pitch,	11¾	=	58·7

On rectification this yields—

	Gallons.		By volume. Per cent.
50 per cent benzol,*	2·88	=	1·47
Solvent naphtha.	2·69	=	1·37
Burning naphtha,	3·51	=	1·79
Total creosote oils,	83 00	=	42·41

* Equal to 90 per cent. benzol, 1·60 gallons = 0·82 per cent.

E. Kopp states that, on an average (French?), coal tar yields the following amount—1 ton = 1000 kilogrammes = 900 litres, yields:—

	Litres.		By volume. Per cent.
Ammoniacal water,	13— 14	=	about 1·5
Very light oils, mostly benzene,.	29— 30	=	" 3 2
Light oils, containing a little benzene, mostly suitable for solvent naphtha,	90—100	=	" 10·5
Creosote oils (distillation carried so far that hard pitch is left),	300—312	=	" 31·2
Do. of soft pitch left.	190—200	=	" 21·7
			By weight.
Anthracene (pure, melting at 210° to 213°)	[Wholly coked?]		" ¾ to 1

The following two estimates are kindly furnished by practical distillers as being fair representations of the average results obtained from English coal tars:—

(A) **Walter Smith** obtained in 1869 the following numbers as the average yield of Lancashire tars. These vary considerably in composition, according to the quality used, the temperature employed in distillation, &c., some containing much napthalene, others but little. The quantity and quality of the carbolic acid obtained also vary much.

1000 gallons (about 5·3 tons, the tar having the sp. gr. 1·16) of tar yield—

	Gallons.		By Weight.
Ammoniacal liquor (containing 4 per cent. ammonia),	25	=	2·2
Light naphtha (first light oils).	28	=	2·2
Second light oils (sp. gr. not higher than that of water),	131	=	10·6
Creosote oils,	87	=	7·6
Anthracene oils,	191	=	16·9
	Tons.		
Residual pitch,	3¼	=	60·5
			100·0

On further rectification, &c., these distillates yield—

		Gallons.
Benzol, (at 90 per cent.),	about	6
Solvent naphtha,	"	74
Carbolic acid,	"	6½
		Cwt.
Anthracene (at 30 per cent.),	"	½
Equal to pure anthracene,	"	0·15

(B) **A. J. Dickinson** gives the following estimate as to the average yield from London tar. 1000 gallons produce—

	Gallons.		By Volume. per cent.
Naphtha (containing 6 per cent. of benzol),	30	=	3
Ammoniacal water,	30	=	3
Anthracene (at 25 per cent),	10	=	1
Pitch,	650	=	65
Creosote, lubricating oils, carbolic acid, &c.,	280	=	28
	1000		100

The following table exhibits, side by side, the more detailed of these results. 1000 gallons of average tar yield—

	Source of Tar and Authority.				
	London. LETHEBY.	London. DICKINSON.	Lancashire. WATSON SMITH.	England. R. F. SMITH.	France. (?) KOPP.
Gallons of ammoniacal liquor,	24	30	25	15	15
" first light oils,	16	30	28	31	137
" second light oils,	12		131	109	
" creosote oils,	288	280	87	337	217
" anthracene oils,			191		95
Tons of pitch,	3 6	3·6	3·25	3·0	—
After rectification and purification—					
Gallons of benzol at 90 per cent., or lower percentaged benzol equivalent thereto,	6·84	—	6	8·2	—
Gallons of naphtha,	5·38	—	74·	31·6	—
" creosote oils (total),	302·	—	—	424·	—
		Cwts.	Cwts.		Cwts.
Pure anthracene, or lower qualities equivalent thereto,	—	0·25	0·15	—	about 0·9 pitch coked(?)

Versmann's estimate of anthracene represents from 0·15 to 0·30 cwt. of *pure* anthracene per 1000 gallons of tar, if the pitch is not coked; and from 0·55 to 1·11 cwt. if wholly coked.

The "creosote oils," produced in somewhat large quantity in the distillation of ordinary British coal tar, constitute a material for which useful applications are still needed. The chief use to which they are at present put is for pickling or creosoting wood (railway sleepers, posts, timber, &c.), to prevent it from decay, or to preserve it from the ravages of insects; but the price commanded for this purpose is so low that many tar distillers simply use them, together with the naphthalene, as fuel underneath the stills,

&c. Attempts have been made to break them up by a sort of destructive distillation into illuminating gases and lighter volatile hydrocarbons, &c., the liquid oils being allowed to flow gently into retorts maintained at a red heat; a graphitoidal coke is formed in the retort, whilst gases of high illuminating quality and a light tar containing much benzene pass off, the latter being condensed by a worm tube or atmospheric condenser. This process is, however, not suitable for the tar distiller himself, but only for the gas-maker, who can utilize the permanent gases constituting the majority of the yield.

The following diagrams (Figs. 17 and 18) illustrate the process whereby these oils are used as fuel underneath the stills, steam boilers, &c:—The oils to be burnt are placed in a vessel, B, on the top of a boiler, A, through which receptacle the steam pipe, C C, passes, so as to keep the oils perfectly liquid, naphthalene and other solid hydrocarbons being dissolved in the hot fluid substances present. By means of taps the steam and the oils are allowed to pass through the pipes E E and C C, to an arrangement, F, of 2-inch iron piping, somewhat similar in construction to a Herapath blow-pipe; the oils are allowed to pass through the interior tube to a nozzle, D, where they are scattered in the form of spray by the jets of steam issuing through the perforations in the nozzle (Fig. 18). The furnace, G, being hot, ignites the issuing jet of spray, &c., and thus a powerful flame is kept up with but little consumption of fuel. The same arrangement may be applied to the still itself instead of a fire.

Fig. 17.

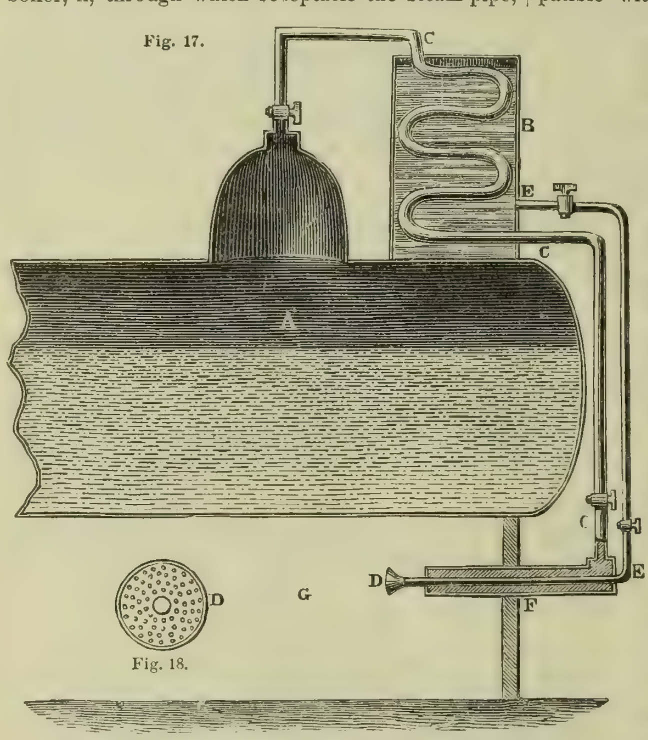


Fig. 18.

In the British colliery districts enormous quantities of coal are converted into coke for the purpose of iron smelting, fuel for locomotives, &c. Many attempts have been made to collect the products of distillation of coal formed during this process, but hitherto to little purpose. In order to produce a hard coke (such as is requisite for iron smelting) a high temperature in the coking oven is essential, and this can only be obtained by the admission of a certain amount of air into the oven, whereby the evolved vapours are burnt almost as fast as generated. Partly owing to the very high temperature at which the partially burnt products of distillation escape into the flues, and partly to the circumstance that any attempt at cooling and condensation of the vapours seriously interferes with the draught, and hence with the effectiveness of the coke oven, it results that the collection of tar products practically is either incompatible with the proper working of the ovens, or costs more than the products obtained are worth. Moreover, it by no means follows that the products of distillation of coal at a high temperature are the same as those formed at a lower temperature; experience shows that the quantity of tarry products is usually less the higher the temperature of distillation. It does not appear that attempts to obtain even ammonia from the volatile products of this kind of coke making have been commercially successful; partly, no doubt, owing to the actually smaller production of ammonia at the higher temperature, partly to the greater or less destruction of that which actually is formed during the partial combustion of the gases evolved in the coke oven itself, and partly from the mechanical and other difficulties in the way of its collection.

In the form of coke ovens now regarded as most effective, the gaseous products are so completely burnt in the ovens and flues that little, if any, visible smoke is emitted; one result of which is that a large proportion of the sulphur expelled from the coal during coking is emitted in the form of sulphurous acid, the destructive action of which (and the sulphuric acid thence resulting by natural oxidation) on the surrounding vegetation is most marked.

It is much to be regretted that the practical difficulties in the way of utilizing the enormous quantities of valuable products (amounting to hundreds of thousands of tons annually in England alone) thus wasted are so great. Were it rendered possible to obtain in saleable form the tarry products of the coal thus employed, and to utilize the vast stores of gaseous fuel thus generated, and immediately burnt to little or no purpose (beyond perhaps raising steam for the immediate purposes of the colliery, baking bricks, &c.), benefit would be conferred on the world at large, the pecuniary value of which would be very great.

Anthracene ($C_{14}H_{10}$). — This hydrocarbon was first obtained by Dumas and Laurent in 1832 in an impure state, a circumstance which led to their attributing to the body a formula polymeric with that of naphthalene, viz., $C_{15}H_{12}$ (naphthalene being $C_{10}H_8$), and applying to it the term *Paranaphthalene;* the product investigated by these chemists melted at 180° C., and distilled at over 300° C. Subsequently Laurent subjected the substance to further examination, and applied to it the name *Anthracene.* In 1857 Fritsche obtained from coal tar a hydrocarbon much resembling the anthracene of Laurent, but melting at 210° to 212° C., and giving numbers in analysis agreeing with the formula $C_{14}H_{10}$. In 1862 Anderson showed that Fritsche's and Laurent's products were identical, and obtained a number of anthracene derivations, notably anthraquinone. In 1866 Limpricht showed by heating chlorobenzyl (C_7H_7Cl) and water to 180° C. anthracene was produced amongst other substances, and in the same year and the following one Berthelot found that anthracene is one of the bodies formed by the action of heat on various simpler hydrocarbons.

In 1868 Grœbe and Liebermann made the discovery from which dates the series of investigations from which the artificial production of madder colours has ultimately sprung, viz., that alizarin is really a derivative of the hydrocarbon anthracene, and is converted into anthracene when heated with finely divided zinc. The discovery of the converse reaction, or the conversion of anthracene into alizarin, soon followed, and thus an entirely new industry was created, viz., the manufacture from long decomposed vegetable matter of the dyestuffs up to that time only obtainable from the natural products of the madder tribe. As soon as a demand for anthracene was created improved processes for its extraction from coal tar were invented; and so rapidly has the new manufacture gained ground that madder cultivation is already seriously threatened.

Besides occurring in coal tar (and possibly in other kinds of tar), or in the products of its redistillation, anthracene can be formed synthetically in various ways; none of which, however, are as yet of practical value for the preparation of the substance. Thus—

(A.) Abstraction of the elements of hydrochloric acid and hydrogen from benzyl chloride (Limpricht's reaction, *supra*):—

$$2C_7H_7Cl = 2HCl + H_2 + C_{14}H_{10}.$$

(B.) Action of heat on various more simple hydrocarbons, whereby hydrogen is evolved (Berthelot) thus:—Styrene (C_8H_8) + benzene (C_6H_6), when heated, give off hydrogen ($2H_2$) and yield anthracene ($C_{14}H_{10}$); two equivalents of toluene ($2C_7H_8$) give off six of hydrogen ($3H_2$) forming alizarin ($C_{14}H_{10}$); and two of benzene + one of ethylene ($2C_6H_6 + C_2H_4$), when heated in like manner, give off six of hydrogen ($3H_2$), anthracene ($C_{14}H_{10}$) being the resulting product.

(C.) Reducing action of nascent hydrogen on alizarin, anthraquinone, &c. Grœbe, Liebermann, &c.:—

$$\overset{\text{Alizarin.}}{C_{14}H_8O_4} + H_2 - O_4 = \overset{\text{Anthracene.}}{C_{14}H_{10}}.$$

$$\overset{\text{Anthraquinone.}}{C_{14}H_8O_2} + H_2 - O_2 = \overset{\text{Anthracene.}}{C_{14}H_{10}}.$$

(D.) Action of oxidizing agents on anthracene hydride and anthracene hexahydride, in each case hydrogen being withdrawn as water:—

$$\overset{\text{Anthracene hydride.}}{C_{14}H_{12}} - H_2 = \overset{\text{Anthracene.}}{C_{14}H_{10}}. \qquad \overset{\text{Anthracene hexahydride.}}{C_{14}H_{16}} - 3H_2 = \overset{\text{Anthracene.}}{C_{14}H_{10}}.$$

When pure, anthracene crystallizes in shining white scales or rhomboidal tables. When obtained by sublimation, it forms a very light mass of pearly white flakes. It melts at 213° C., and distils at close upon 360° C. Carbon disulphide dissolves 1·7 per cent. of anthracene, cold benzene 0·9 per cent., and alcohol somewhat less, 0·6 per cent. In water and aqueous alcohol anthracene is insoluble, and in petroleum light distillates it dissolves even less than in benzene. With picric acid it forms a characteristic compound crystallizing in ruby-red needles; and with an alcoholic or benzene solution of dinitro anthraquinone it forms reddish-violet rhomboidal scales. Nascent hydrogen (alcohol and sodium) unites with it, forming *anthracene hydride* ($C_{14}H_{12}$), which is again converted into anthracene by certain oxidizing agents, and forms *anthracene hexahydride* by the reducing action of hydriodic acid at 200° to 220° C. Chlorine attacks anthracene, forming *dichloranthracene* ($C_{14}H_8Cl_2$) and also *dichloranthracene tetrachloride* ($C_{14}H_8Cl_6$ or $C_{14}H_8Cl_2,Cl_4$). According to Anderson, *monochloranthracene* ($C_{14}H_9Cl$) and *anthracene dichloride* ($C_{14}H_{10}Cl_2$) also exist. *Trichloranthracene* ($C_{14}H_7Cl_3$) is got by the action of phosphorus pentachloride on anthraquinone. By the action of alkalies on dichloranthracene tetrachloride the elements of hydrochloric acid are removed, and *tetrachloranthracene* ($C_{14}H_6Cl_4$) is produced. Bromine forms similar compounds; thus *dibromanthracene* ($C_{14}H_8Br_2$) *tetrabromanthracene* ($C_{14}H_6Br_4$), *dibromanthracene tetrabromide* ($C_{14}H_8B_2.Br_4$), and *tribromanthracene* ($C_{14}H_7Br_3$) are known.

Oxidizing agents (*e.g.*, chromic acid), act energetically on anthracene and its substitution derivatives, forming *anthraquinone* or its derivatives, thus:—

$$\overset{\text{Anthracene.}}{2C_{14}H_{10}} + 3O_2 = 2H_2O + \overset{\text{Anthraquinone.}}{2C_{14}H_8O_2}$$

$$\overset{\text{Dibromanthracene.}}{C_{14}H_8Br_2} + O_2 = Br_2 + C_{14}H_8O_2$$

$$\overset{\text{Tribromanthracene.}}{C_{14}H_7Br_3} + O_2 = Br_2 + \overset{\text{Bromanthraquinone.}}{C_{14}H_7BrO_2}$$

Strong nitric acid forms anthraquinone and *dinitro anthraquinone*, $C_{14}H_6(NO_2)_2O_2$; in alcoholic solution, however, anthracene is converted by this agent into *mononitro anthracene*, $C_{14}H_9(NO_2)$; a *dinitro anthracene* ($C_{14}H_8(NO_2)_2$) also exists.

Concentrated sulphuric acid, especially the fuming acid, dissolves anthracene with the production of *anthracene mono-* and *di-sulphonic acids*, $C_{14}H_9(HSO_3)$, and $C_{14}H_8(HSO_3)_2$ respectively; these are readily converted by oxidizing agents into *anthraquinone mono-* and *di- sulphonic acids*, $C_{14}H_7O_2(HSO_3)$ and $C_{14}H_6O_2(HSO_3)_2$ respectively. Similarly, dichloranthracene and dibromanthracene form with fuming sulphuric acid *dichloranthracene sulphonic acid* $(C_{14}H_6Cl_2(HSO_3)_2$ and *dibromanthracene sulphonic acid* $(C_{14}H_6Br_2(HSO_3)_2$ respectively. Oxidizing agents readily convert these into *anthraquinone disulphonic acid*, hydrochloric (or hydrobromic) acid being disengaged.

By the action of nitric acid, or of strong sulphuric acid, on the product of the action of chlorine on anthracene, SCHÜTZENBERGER has obtained a red substance isomeric with anthraquinone, but differing from it in being insoluble in ammonia and caustic alkalies; when heated to 300° C. it becomes converted into ordinary yellow anthraquinone.

Of these and numerous other anthracene derivatives, a few only have a special commercial interest, from serving as intermediate products in the transformation of anthracene into madder colours.

VERSMANN gives the following table of solubility of anthracene in various liquids at 15° C.:—

	Per cent. Anthracene at 15°.	
	By volume.	By weight.
Alcohol of specific gravity, 0·800....	0·472	0·591
" " 0·825....	0·424	0·574
" " 0·830....	0·408	0·491
" " 0·835....	0·397	0·475
" " 0·840....	0·387	0·460
" " 0·850....	0·360	0·423
Ether..............................	0·858	1·175
Chloroform, ...	2·587	1·736
Carbon disulphide,...................	1·180	1·478
Glacial acetic acid,.................	0·472	0·444
Benzol,.............................	1·470	1·661
Petroleum,..........................	0·291	0·394

Manufacture of Anthracene.—The coal tar distiller sends into the market a rough product under the name of anthracene, which is simply obtained by collecting apart a certain portion of the coal tar distillate, which he terms anthracene oil. This is allowed to stand in tanks until the solid hydrocarbons have separated as completely as possible, and the deposited matter filtered off through sackcloth or stout canvas bags, the mother liquors being finally squeezed out by hydraulic pressure, or by a centrifugal machine, followed by hydraulic pressure. This crude product contains from 30 to 60 per cent. of actual anthracene. The mother liquors, which run off during the filtration and pressure, are collected and distilled somewhat after the fashion of the original coal tar, but on a smaller scale. The first portions of distillate are rejected, the higher portions worked up over again, just as the "anthracene oil" itself. The anthracene from the mother liquors contains a considerably smaller percentage of pure anthracene than the first crop of solid hydrocarbons. Frequently it is desirable to raise the quality of the product by hot pressure. The mass is steamed, and then subjected to hydraulic pressure while still hot. In this way naphthalene, and substances of low melting point, are much more thoroughly expressed than by simple cold pressure. This process of hot pressure may with advantage be applied to the cold-pressed anthracene obtained from the anthracene oil, a substance of higher percentage being thereby obtained. In England, however, it does not seem to be adopted, save for very inferior kinds. The crude anthracene thus obtained usually contains more or less of the following ingredients:—

A.—Hydrocarbons.—1. Solid at the ordinary temperature:—Anthracene, $C_{14}H_{10}$; naphthalene, $C_{10}H_8$; pyrene, $C_{16}H_{10}$: chrysene, $C_{18}H_{12}$; retene. $C_{18}H_{18}$; phenanthrene, $C_{14}H_{10}$; acenaphthene, $C_{12}H_{10}$. Benzerythrene, bitumene, &c. 2. Liquid hydrocarbons of high boiling point.

B.—Bodies not hydrocarbons:—Acridene, $C_{12}H_9N$, or $C_{24}H_{18}N_2$; carbazol, $C_{12}H_9N$.

Crude anthracene is valued by means of a rough method of proximate analysis, depending on the differences in the solubility in the various menstrua of pure anthracene, and the various products which accompany it, the latter being dissolved out and the former left. Unfortunately it is impracticable by this means to obtain any accurate determination of the actual quantity of pure anthracene present, the results obtained with various solvents exhibiting great discrepancies; but inasmuch as tolerably accurate values can be obtained when some one process is rigidly adhered to, this mode of procedure can be used for technical purposes. It is, however, absolutely essential that every minute detail of the testing process should be previously agreed upon between buyer and seller. Thus, if the substance tested be oily, and be pressed before testing, a higher value is found, as the oily portion, if not removed, enables the solvent to take up more anthracene. The nature of the solvent (alcohol or carbon disulphide), the exact specific gravity of the alcohol (if the former be used), the quantity of solvent to be employed, and the exact mode of manipulation to be followed, must all be expressed in the contract.

The following description of the modes of testing commercial anthracene now employed is obligingly communicated by F. A. MANNING:—

Alcohol Test.—The sample is thoroughly mixed in a mortar, and 20 grammes are taken out and thoroughly stirred with 150 c.c. of alcohol, of the strength stated in the contract; the beaker is covered with a watch glass, gently heated to boiling, and allowed to cool to 60° Fahr., standing in water. After one hour's standing the liquor is decanted on to a filter, and the insoluble matter gradually washed with alcohol of the original strength at 60° Fahr., until the filtrate and washings measure 400 c.c. Should any visible sand be at the bottom of the beaker it is kept back; the insoluble part is then conveyed to a weighing glass and dried in a water bath at 212° Fahr. The weight of the residue, multiplied by 5, gives the percentage of so-called anthracene, and is the basis for payment.

The melting point is taken in a narrow glass tube, drawn out to a fine point; into this the anthracene is put to the depth of about 1 inch; it is then immersed, together with an accurate thermometer (or one the index errors of which are known by comparison with a standard thermometer), in melted paraffin, and the point at which the first drop runs down is taken as the melting point. After complete liquefaction the lamp is removed from under the paraffin bath, and the temperature at which solidification takes place is noted; the mean between the former melting point and this temperature is then taken as the *mean melting point;* this should not be below 190° C.

Or, the quantity of substance melting at 190° C. (or some other fixed point) is determined, the specific gravity of the alcohol used being stipulated (usually 0·825), but not the quantity. A sample is treated as above, and the melting point determined. Should this be 190° C., nothing further is requisite; but if different, another test is made with a different quantity of alcohol (less if the melting point of the second specimen is to be above that of the first, more if *vice versa*). For instance—suppose No. 1 is boiled with 150 c.c. of alcohol and washed to 400 c.c., and gives a certain percentage, say 40, melting at 195° C.; No. 2 is boiled with 100 c.c. and washed to 300 c.c.; this gives a larger percentage (say 49) with necessarily a lower melting point, say 188° C. Then the quantity of substance melting at 190° C. is found by the proportion:—

$$195 - 188 : 49 - 40 :: 195 - 190 : x,$$

where x is the amount to be added to the lower percentage to give the percentage of substances melting at 190°. In the instance quoted

$$x = \frac{9 \times 5}{7} = 6{\cdot}4,$$

therefore the sample contains 40 × 6·4 = 46·4 of substance melting at 190° C.

Carbon Disulphide Test.—Ten grammes of the thoroughly mixed sample are shaken in a well-stoppered bottle with 30 c.c. of carbon disulphide, and allowed to stand for one hour at 60° Fahr. The insoluble matter is then thrown upon a filter, and the bottle washed out with 30 c.c. more of disulphide, any sand being kept back. After the liquid has run through the filter it is gently and quickly pressed between the fingers, and afterwards between blotting paper in a strong press. The insoluble matter is then transferred to a watch glass, dried for an hour at 100° C., and weighed; the weight multiplied by 10 gives the percentage. The mean melting point of a sample thus examined should not exceed 212° to 214° C.

The following tables illustrate the results of the tests of 400 different samples of crude anthracene by the alcohol test, and 250 by the carbon and disulphide test:—

ALCOHOL TEST.

About	12	per cent.	of the total number of samples contain, of so-called anthracene, *i.e.*, insoluble matter in alcohol, less than 20	per cent.
"	20	"	between 20 and 30	"
"	27	"	" 30 and 40	"
"	21	"	" 40 and 50	"
"	12	"	" 50 and 60	"
"	8	"	above 60	"

CARBON DISULPHIDE TEST.

About	6	per cent.	contain	less than 10	per cent.
"	20	"	"	between 10 to 20	"
"	39	"	"	" 20 to 30	"
"	22	"	"	" 30 to 40	"
"	8	"	"	" 40 to 50	"
"	5	"	"	above 50	"

As regards melting point, these tests give the following results:—

Melting Point.	Alcohol Test.	Carbon Disulphide Test.
	Per Cent.	Per Cent.
Below 190° C.	About 38	—
190° to 195°	48	—
195° to 200°	12	About 2
Above 200°	2	—
200° to 205°	—	23
205° to 210°	—	48
210° to 215°	—	23
215° to 218°	—	4

The relation between the results of these two sorts of test is by no means constant. VERSMANN gives the following table of comparative results obtained by the duplicate examination of thirty samples:—

Alcohol test.		Carbon disulphide test.	
Per cent.	Melting point. Degs. C.	Per cent.	Melting point. Degs. C.
20	154	5	212
20	184	5	204
22	165	5	218
25	177	13	209
27	187	18	207
27	183	15	208
28	181	13	209
30	184	10	208
32	184	21	205
35	183	21	209
36	181	18	202
38	180	22	203
41	184	27	208
42	188	28	211
43	191	31	204
44	189	32	207
46	192	31	209
47	188	32	207
50	192	36	207
51	198	42	212
53	194	36	209
54	157	10	204
56	185	40	201
57	189	43	205
58	183	41	201
59	190	42	203
61	198	50	211
64	200	61	208
69	201	64	208
72·5	211	74	213

With low percentages the alchohol test gives a result four times as high as the carbon disulphide plan. With higher percentages the discrepancy becomes less and less, the alcohol test uniformly giving a higher value up to near 70 per cent., when the two processes nearly agree; the result of the alcohol test on the last case examined being actually lower than that of the carbon disulphide.

To remedy these inconveniences another test has been proposed by E. LUCK, and also by PAUL and COUNLEY, depending on the oxidation of anthracene to anthraquinone, and the solubility by alkaline solutions of the oxidation products of the hydrocarbons present other than anthracene. This may be worked as follows:—Heat in a flask 1 gramme of anthracene together with 45 c.c. of glacial acetic acid till it quietly boils; add gradually, and at intervals of five to ten minutes, a solution of 10 grammes of chromic acid in 5 c.c. of glacial acetic acid and 5 of water. To prevent any loss of acetic acid during boiling, the flask is furnished with a condenser, which allows the acid constantly to flow back. About two hours' gentle boiling in most cases completes the decomposition, after which allow the flask to cool, add 150 c.c. of water, and allow it to stand for a couple of hours. Light yellow needles of anthraquinone then separate from the green liquid. Bring the whole on a filter, wash the crystalline residue first with water, then with a very dilute, hot solution of potash, until the liquid runs off perfectly colourless; and lastly, again with water, to remove traces of alkali. Now dry the filter in a water bath, and when perfectly dry detach the anthraquinone with a spatula, and weigh. This last direction is given in preference to weighing the residue and filter, because it has been found that the dilute chromic and acetic acid dissolve part of the filter paper, the original weight of which would be thereby altered.

The quantity of acetic acid and water used in this process dissolve 0·010 gramme of anthraquinone, = 1 per cent. on the weight taken; this amount must, therefore, be added to the percentage found. Hitherto this process has not come into use to any extent in the English trade, but it seems probable that it may eventually do so.

Refining.—Before anthracene of the ordinary English qualities can be used for colour-making it must be purified. The tar distillers usually prefer to manufacture very rough products. The colour maker prefers to purchase a refined article rather than to have the trouble of refining the crude article himself. An intermediate class of manufacturers, viz., anthracene refiners, has therefore sprung up. The processes employed by them, as far as they are known, appear to consist of cold and hot pressing, and washing with various solvents, notably the distillates from petroleum, boiling at towards 90° C. (not above 100°, on account of the greater solubility of anthracene in such distillates, and the increased difficulty in removing the last traces of the washing liquid used). By these means the majority of the impurities present are washed out with but little waste of anthracene, and a partially purified anthracene of 75 or 80 per cent. is obtained. Sometimes the petroleum distillate is used at a boiling temperature. There seems to be no reason why this part of the refining process at least should not be carried out by the tar distiller, who can work up mother liquors and bye products much more readily than an anthracene refiner, to whom everything that is not anthracene is a waste material.

For the final purification SCHULER recommends distillation, or rather sublimation, a current of air being driven into the retort. Tolerably pure anthracene is driven over, and condenses in yellowish snow-like flakes, a form which is peculiarly adapted to oxidation. To complete the purification the sublimed powder is boiled with freshly distilled petroleum, boiling at 120° to 150° C., and filtered and well pressed. When chemical purity is requisite, the product is crystallized two or three times from alcohol, dried, sublimed very slowly, and the sublimate washed with ether, which removes the last traces of an adhering yellowish product; this may also be removed by dissolving in hot benzol and bleaching by sunlight.

Anthraquinone ($C_{14}H_8O_2$), *and its Derivatives.*—Anthraquinone itself (the *anthracenuse* of LAURENT and the *oxanthracene* of ANDERSON) is most conveniently obtained by acting on anthracene dissolved in glacial acetic acid with chromic acid. On a manufacturing scale sulphuric acid and potassium dichromate are employed; or nitric acid, either alone or along with acetic, may be used. The oxidized mass is washed and dried and then sublimed: when pure it melts at 273° C.

Anthraquinone varies in colour somewhat, according to the mode of preparation adopted. It is usually more or less yellow or reddish yellow, but can be obtained almost white by solution in sulphuric acid, and precipitation of the solution by water. Nitric acid of spec. grav. 1·4 dissolves it unchanged; but a mixture of nitric and sulphuric acids forms *dinitro anthraquinone* ($C_{14}H_6(NO_2)O_2$). The long-continued action of dilute acid also forms a dinitro anthraquinone; so that when heated for a long time with sulphuric acid it forms *mono-* and *di- anthraquinone-sulphonic acids*, respectively $C_{14}H_7(HSO_3)O_2$, and $C_{14}H_6(HSO_3)_2O_2$. When fused for a long time with caustic potash, oxygen is taken up and alizarin is formed; a complete decomposition is, however, produced in this case, benzoic acid being formed, and at a certain stage of the operation a non-crystalline citron-yellow product, probably *anthraquinhydrone*, $C_{28}H_{16}O_4$.

Zinc dust (containing zinc hydrate), when heated with anthraquinone, converts it into anthracene, as does also a mixture of zinc and hydrochloric acid. Bromine acts on anthraquinone in sealed tubes at 160° C., forming dibromanthraquinone, identical with that produced from tetrabromanthracene by oxidizing agents. Chlorine acts in a similar manner in forming dichloranthraquinone.

Alizarin ($C_{14}H_8O_4$). — The two most important anthraquinone derivatives, alizarin and purpurin, are respectively a di- and tri- hydroxylated anthracene.

Alizarin acts as a weak dibasic acid; thus its calcium salt is indicated by the formula $C_{14}H_6O_2(CaO_2)$; analogous barium, aluminium, and other salts are known. By the action of ethyl iodides on sodium alizarate, *diethyl alizarate*, $C_{14}H_6O_2(OC_2H_5)_2$, is produced, whilst monomethyl alizarin, $C_{14}H_6O_2(OH)(OCH_3)$, and monoethyl alizarin, $C_{14}H_6O_2(OH)(OC_2H_5)$, are obtainable by the action on alizarin of a mixture of caustic potash, alcohol, and methyl or ethyl iodide (SCHUNCK). Benzoyl chloride acts on alizarin, forming *dibenzoyl* alizarin, $C_{14}H_6O_2(O.C_7H_5O)_2$ and acetic anhydride gives rise to diacetyl alizarin, $C_{14}H_6O_2(O.C_2H_3O)_2$. Fuming sulphuric acid forms *alizarin monosulphonic acid*, $C_{14}H_5(HSO_3)O_2(OH)$; on fusion with caustic potash this forms potassium sulphate and reproduces alizarin, and does not (as might have been expected) give rise to potassium sulphite and an oxy-alizarin.

The conversion of anthracene into alizarin may be accomplished in several ways, in some of which anthracene is not itself used as an intermediate product. These methods may be summarized as follows:—

(A.) Original process patented by GRŒBE and LIEBERMANN in 1868. Anthracene is first converted into anthraquinone by either of the following processes:—(1.) Treatment of 1 part anthracene with 2 of potassium dichromate and sulphuric acid, with or without the addition of strong acetic acid. (2.) Oxidation of anthracene by dichromate, both dissolved in glacial acetic acid. (3.) Oxidation by nitric acid of medium strength, acetic acid being also added.

The anthraquinone thus obtained is purified and converted into *dibromanthraquinone* by treatment with 4 equivalents of bromine in closed vessels at 80° to 130° C. thus—

$$\overset{\text{Anthraquinone.}}{C_{14}H_8O_2} + 2Br_2 = \overset{\text{Dibromanthraquinone.}}{C_{14}H_6Br_2O_2} + 2HBr.$$

The resulting dibromanthraquinone is then heated to between 180° and 260° C. with a concentrated solution of caustic soda or potash in closed vessels, when the following reaction takes place, potassium alizarate being formed, from which alizarin is produced by the action of acids.

$$\overset{\text{Dibromanthraquinone.}}{C_{14}H_6Br_2O_2} + \overset{\text{Potassium hydrate.}}{4KOH} = \overset{\text{Potassium bromide.}}{2KBr} + \overset{\text{Potassium alizarate.}}{C_{14}H_6O_2(OK)_2} + 2H_2O.$$

$$\overset{\text{Potassium alizarate.}}{C_{14}H_6O_2(OK)_2} + \overset{\text{Hydrochloric acid.}}{2HCl} = \overset{\text{Potassium chloride.}}{2KCl} + \overset{\text{Alizarin.}}{C_{14}H_6O_2(OH)_2}.$$

The "melt" is dissolved in water, and hydrochloric or sulphuric acid added, upon which the alizarin is thrown down in flakes, which are collected, washed, and drained, and sent into the market as a paste.

In the same way dichloranthracene may be prepared from anthracene and chlorine, and converted into alizarin.

In a subsequent patent GRŒBE and LIEBERMANN avoid the necessity of producing anthraquinone, by treating anthracene itself with 8 equivalents of bromine, when dibromanthracene tetrabromide is formed—

$$\overset{\text{Anthracene.}}{C_{14}H_{10}} + 4Br_2 = 2HBr + \overset{\text{Dibromanthracene tetrabromide.}}{C_{14}H_8Br_2,Br_4}.$$

The product is then heated with alcoholic potash, and is converted into tetrabromanthracene.

$$\overset{\text{Dibromanthracene tetrabromide.}}{C_{14}H_8Br_6} = 2HBr + \overset{\text{Tetrabromanthracene.}}{C_{14}H_6Br_4}.$$

By the action on this of 5 parts of slightly dilute nitric acid at 100° C. dibromanthraquinone is formed and bromine set free:—

$$\overset{\text{Tetrabromanthracene.}}{C_{14}H_6Br_4} + O_2 = \overset{\text{Dibromanthraquinone.}}{C_{14}H_6Br_2O_2} + Br_2.$$

This dibromanthraquinone is then converted into alizarin as before. Chlorine may be substituted for bromine in this case also.

(B.) Process patented by BRŒNNER and GUTZKOW. Anthracene is converted into anthraquinone by nitric acid of sp. gr. 1·3 to 1·5, and the product purified; the anthraquinone is then heated with sulphuric acid, and mercuric nitrate added. The product of the action is dissolved in a caustic alkaline solution, filtered, and saturated with an acid; a precipitate containing both alizarin and purpurine (anthrapurpurine) being thrown down. Although this patent is not clearly worded, yet it points out that sulphonic acid can be used in lieu of bromine, and hence is really the foundation of the more recent processes for the manufacture of artificial alizarin (C). The mercuric nitrate oxidizes the anthracene disulphonic acid first formed to anthraquinone disulphonic acid, and then becomes converted into alizarin by the alkali. To obtain a profitable amount of product, however, excess of alkali must be used, the whole evaporated to dryness, and the residue fused, an operation not mentioned in the patent specification.

(C.) In June, 1869, GRŒBE, LIEBERMANN, and CARO patented the following process:—Anthraquinone is heated with sulphuric acid, whereby anthraquinone disulphonic acid is formed. Excess of sulphuric acid is then removed by means of chalk, sodium carbonate added, and the resulting sodium anthraquinone disulphonate fused with 2 to 3 parts caustic soda, producing alizarin thus:—

$$\overset{\text{Anthraquinone disulphonic acid.}}{C_{14}H_6O_2(HSO_3)_2} + \overset{\text{Sodium hydrate.}}{4Na(OH)} = \overset{\text{Sodium sulphate.}}{2Na_2SO_3} + 2H_2O + \overset{\text{Alizarin.}}{C_{14}H_6O_2(OH)_2}.$$

This patent was dated June 25 (England). On the next day W. H. PERKIN took out a patent for nearly the same process. This chemist also observed that oxyanthraquinone monosulphonic acid is formed, $C_{14}H_6O_2\left\{\begin{matrix}SO_3H,\\ OH\end{matrix}\right.$ as an intermediate product between the disulphonic acid and alizarin. This gives the blue cast to the "melt." Perkin has also patented the production of anthraquinone disulphonic acid by the oxidation of the chloro- and bromo-sulphonic acids formed by acting with sulphuric acid on chlorinated and brominated anthracene.

(D.) In a subsequent patent GRŒBE, LIEBERMANN, and CARO obtain anthraquinone disulphonic acid, without the previous preparation of anthraquinone, by treating anthracene with sulphuric acid, and oxidizing the resulting anthracene disulphonic acid with manganese dioxide or some other oxidizing substance.

$$\overset{\text{Anthracene disulphonic acid.}}{2C_{14}H_8(HSO_3)_2} + 3O_2 = \overset{\text{Anthraquinone disulphonic acid.}}{2C_{14}H_6O_2(HSO_3)_2} + 2H_2O.$$

To prepare the anthraquinone disulphonic acid in this way, 1 part of anthracene and 4 of strong sulphuric acid are heated to 100° C. for about three hours, the temperature being then raised to 150° C. or upwards for another hour or more. Three parts of water are added to the product after cooling, when unaltered anthracene is precipitated, which is collected and used over again. The acid filtrate is heated to boiling, and 3 parts of powdered manganese dioxide added gradually. The whole may be advantageously evaporated to dryness and heated for some time. The resulting mass is dissolved in boiling water. Milk of lime is added till alkaline and manganous oxide are thrown down. The solution of calcium anthraquinone disulphonate thus produced is strained off from gypsum, &c. (the solid mass being washed and pressed), and decomposed by sodium carbonate. The filtered solution of sodium salt is evaporated to dryness and fused with caustic soda.

(E.) On January 24, 1870, DALE and SCHORLEMMER patented the following process :—Anthracene is *boiled* with 4 to 10 parts of strong sulphuric acid (the action consequently takes places at a higher temperature than in the preceding method). The product is converted into a barium, calcium, potassium, or sodium salt, which is purified by re-crystallization. To a solution of one of these salts excess of caustic soda or potash, and a quantity of nitrate or chlorate of potassium equal to the weight of anthracene, is added. The whole is then evaporated to dryness, and heated to 180° to 260° C., when a blue violet colour appears. From the "melt" alizarin is extracted by solution in water, and addition of a mineral acid in the usual way. In this case the anthracene disulphonate becomes oxidized to anthraquinone disulphonate by the nitrate or chlorate, and the product is converted into alizarin by the caustic alkali.

(F.) MEISTER LUCIUS and BRUNING prepare anthraquinone by oxidizing anthracene with a mixture of nitric acid and potassium dichromate. From this nitro-anthraquinone is formed by the action of nitric acid. On treatment with alkali alizarin is produced, mixed with a little purpurin (anthrapurpurin.)

(G.) GIRARD prepares impure tetrachloranthracene by acting on anthracene with a mixture of hydrochloric acid and potassium chlorate. This is oxidized by nitric acid or by red oxide of lead, and either sulphuric or acetic acid. Dichloranthraquinone and chloroxanthranyl chloride result. The mixture is then treated with oxide of zinc, lead, or copper, and alcoholic sodium acetate, when alizarin is formed. The alizarin thus produced may be purified by treatment with benzol, petroleum distillates, or other solvents by which the foreign matters can be dissolved out; or the alizarin may be dissolved in an alkaline solution, and reprecipitated (after filtration) by an acid, the process being repeated several times.

The preparation of alizarin by any of these processes is a matter of some delicacy. If too high a temperature be attained, the alizarin already formed is more or less destroyed, benzoic acid and other products being formed; whilst the anthraquinone disulphonic acid is more or less converted back again to anthraquinone, or even into anthracene. In the processes by which anthraquinone disulphonic acid is formed, if the heating be not continued long enough, or if the temperature be not high enough, considerable loss is occasioned by the formation of the intermediate oxyanthraquinone sulphonic acid. In process (E), if too much nitrate or chlorate be used, the alizarin is apt to be further acted on and destroyed; whilst if too little be employed, then loss is occasioned by incomplete oxidation. Under certain not well understood circumstances anthraquinone mono-sulphonic acid is formed during the melting, from which results oxyanthraquinone instead of alizarin. The same substance is formed if anthracene mono-sulphonic acid has been formed through the incomplete action of sulphuric acid on anthracene in processes (D) and (E), or if anthraquinone mono-sulphonic acid has been produced through the incomplete action of sulphuric acid on anthraquinone in process (C).

Manufacture of Alizarin. — The method first used in England was that which is now called the anthraquinone process; but owing to the great difficulty in obtaining sufficiently pure anthracene, after a few trials it was abandoned in favour of the chloranthracene process, which was found to give much better results.

The anthracene used for the manufacture of alizarin by the latter process is chiefly obtained from the dead oils of coal tar; an inferior kind is produced from the distillation of pitch, but is not well adapted to the purpose on account of the difficulty in removing the higher series of hydrocarbons. The dead oils from different coals vary considerably in the amount of anthracene they yield. Those obtained from coal in the neighbourhood of Staffordshire contain the most, and the Scotch coals the least. In the fractional distillation of the dead oils a large amount of naphthalene is deposited in the first portions, the anthracene occurring more abundantly towards the middle of the operation; towards the end the anthracene becomes more or less contaminated with the higher series of hydrocarbons, according to the degree the distillation is pushed. Only practice will enable the operator to determine at what point it is best to collect the anthracene, both the first and latter portions of the distillate being returned to the still for further fractionating.

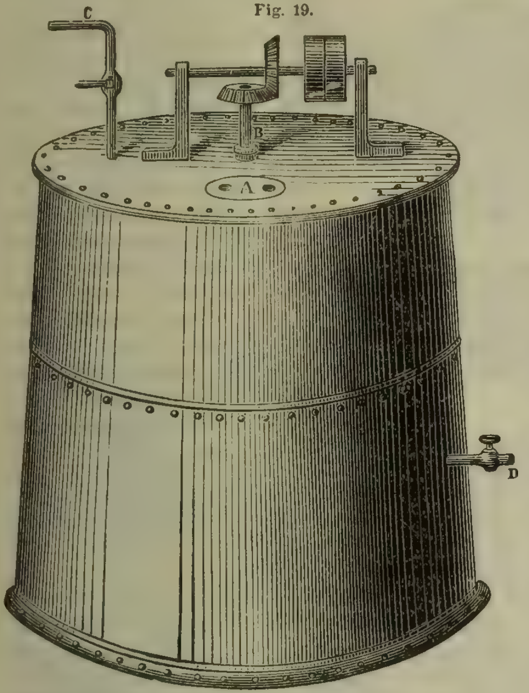
On cooling, those portions of the oil which have been set aside deposit the anthracene as a sandy precipitate of a green colour. When the tanks are cold, or nearly so, the anthracene is scraped off the sides of the tank, and the oils loaded with the deposited anthracene are filtered through canvas bags hung over open tanks, into which the oils drain and are stored for further distillation. After sufficient draining the bags are detached from the frames in which they hung, and folded for the hydraulic press. After pressure has been applied the bags are taken out, and the anthracene appears in the form of a hard greenish cake.

Some tar distillers remove a further portion of the oily impurities by hot pressure. This method of purification is not much in vogue, however, on account of the solubility of the anthracene itself in its own impurities at an elevated temperature.

As the anthracene prepared with or without hot pressure is much too impure to be used for the production of colour, it is necessary that the solid impurities (*e.g.*, naphthalene, phenanthrene) be got rid off by washing with oils or naphtha. This purification is accomplished in the following manner.

The cakes of crude anthracene are first crushed under edge-runners, and ground into a thick paste. This paste is then removed in boxes and drawn up to the top of the building, and transferred from thence into a large jacketed vessel (Fig. 19) of wrought iron of cylindrical form, and about 6 feet high and 5 in diameter. This vessel is closed with the exception of a door on the top, A, by which the anthracene paste is admitted, and is provided with an iron stirrer, B, which passes through a stuffing box and is driven by machinery. The apparatus having been about half filled with American light oils by the oil cock, C, the paste is then stirred in, a little steam being admitted within the jacket to assist the incorporation. When the oil boils the contents are run out into tanks to cool for one or two days.

Fig. 19.



After cooling the tanks are stirred up and the thick liquid is run into a large iron tank, containing a false bottom of wood pierced with holes, and covered with canvas, through which the oils laden with the soluble impurities of the anthracene percolate, running off into a large closed receiver placed underneath the filter.

The oils thus filtered are pumped from the receiver into a large still heated by steam. The oils are distilled off and are condensed in a leaden worm attached to the still, and run into a receiver on the ground floor. The impurities are then run off into a separate tank, and on cooling become solid.

The anthracene remaining on the filter is then raked out from manholes in the sides, and placed in a still, the adhering oils being driven off by a current of steam.

In this state the anthracene presents the appearance of a blackish green powder; but before submitting it to the action of chlorine, it is necessary to remove certain impurities which would interfere with the production of good crystals of chloranthracene. In order to accomplish this the anthracene is distilled with from 15 to 20 per cent. of caustic potash, soda not being found to answer the purpose. The distillation is conducted in gas retorts (Fig. 20), which may be set in benches of three. The potash broken in small pieces is ground under edge-runners with the anthracene. The necks of the retorts, A, are connected with long sheet-iron receivers, B, provided with loosely fitted lids, so that the gases evolved during the distillation may have free vent in case of their taking fire from the overheating of the retorts. Sections of a retort and receiver are shown in Fig. 21.

The retorts being charged with about 2 cwts. of the mixture, are then heated by the furnace, and at a heat short of redness the anthracene distils over and condenses in the receivers, partly in the form of a crystalline cake, and partly in a light sublimate of a pale yellow colour. The impurities are left in the retort combined with the potash as a porous black mass, which after removal readily takes fire on exposure to the air, and continues to burn until all the carbon is consumed, leaving the potash in the form of carbonate, which is reconverted into caustic potash for use in subsequent operations. The anthracene thus obtained is ground under edge-runners and placed in wooden trays, which are arranged on shelves in a drying room.

Fig. 20.

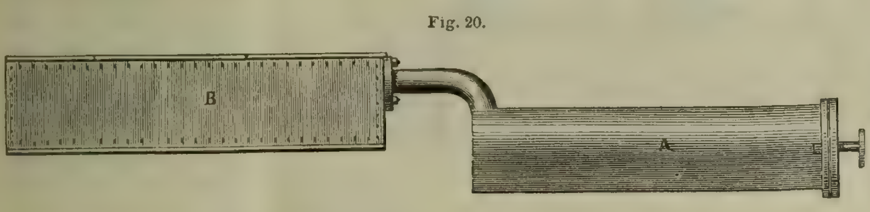
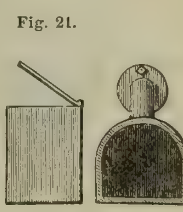
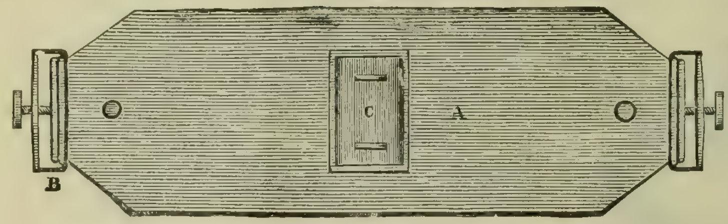


Fig. 21.



When perfectly dry it is ready to be submitted to the action of chlorine, and for that purpose it is placed in about 3 cwt. charges in an oblong leaden receptacle, A (Fig. 22), 10 feet in length, 5 in breadth, and about 18 inches deep, supported by woodwork. At each end of the apparatus a door, B B, is fixed with a screw and crossbar, in the manner of a gas retort lid. The anthracene is introduced by an aperture, C C, on the top of the vessel, which is closed by a leaden cover, the sides of which dip into a channel formed round the opening, filled with dead oils in the manner of a water lute, see section Fig. 23, which also serves as a safety valve in the case of the chlorine being admitted too rapidly. The apparatus is supported by iron plates, under which steam is admitted in order to assist the reaction. The chlorine is admitted from either end of the apparatus, and after traversing the vessel the hydrochloric acid gas and excess of chlorine are conducted by a leaden pipe from the other end into another similar vessel also filled with anthracene, which readily takes up the excess of chlorine. The hydrochloric acid gas is then conducted into a flue connected with a scrubber filled with coke and supplied with water, which condenses the gas, the acid thus condensed being used for the elimination of chlorine. As soon as the anthracene in the first vessel has been entirely converted into chloranthracene, the product is raked out from the doors at each end into wooden tubs; and a fresh charge having been introduced, the leaden pipes which conduct the chlorine are reversed, the chlorine being passed over the second vessel. The excess of chlorine and hydrochloric acid gas, after traversing the first vessel containing the new charge, escapes as before into the flues connected with the scrubber. A sketch showing the two vessels connected is given in Fig. 24, the wooden supports and a portion of the brickwork being removed for clearness.

Fig. 22.



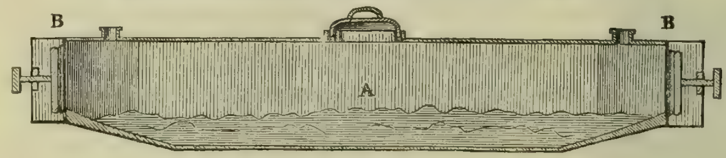
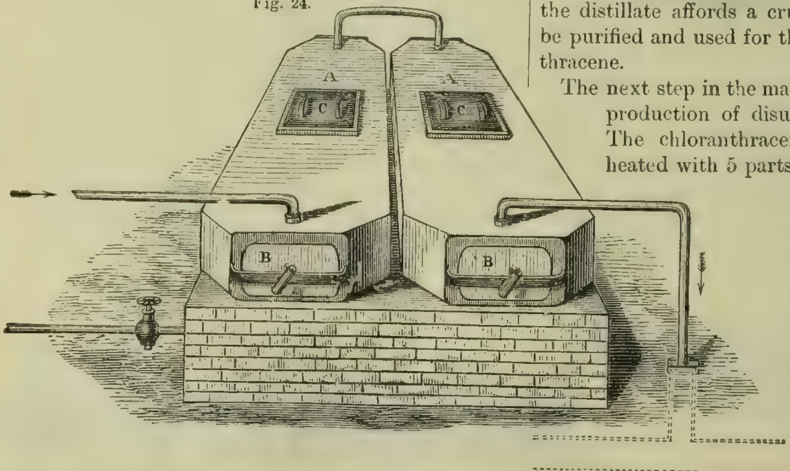


Fig 23.

Fig. 24.



In the production of chloranthracene it is necessary that the anthracene oil used in the operation should not contain more than 50 per cent. of pure anthracene, as the impurities associated with it are necessary for its solution whilst absorbing the chlorine. If purer anthracene were employed only a partial combination would be effected, as the anthracene remaining undissolved would only be superficially attacked.

When removed from the apparatus the chloranthracene presents the appearance of a black sludge, and hardens on cooling. The hydrochloric acid associated with it is neutralized by a solution of caustic soda; and when heated by steam the semi-fluid mass is ladled out into bags, which are submitted to hydraulic pressure whilst hot, until the oils are as far as possible removed. The chloranthracene then appears as brownish-yellow crystalline cake. This is further purified by breaking it up and mixing it with naphtha, pressing it, and repeating the operation once or twice, until the substance has assumed the appearance of a golden yellow friable cake: it is then crumbled up and dried. This should contain from 80 to 90 per cent. of pure chloranthracene.

The oils which exude from the crude chloranthracene are distilled with lime in cast-iron retorts; and the distillate affords a crude anthracene which may be purified and used for the manufacture of chloranthracene.

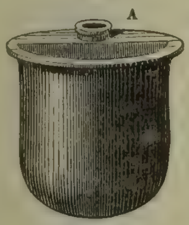
The next step in the manufacture of alizarin is the production of disulpho-anthraquinonic acid. The chloranthracene, purified as above, is heated with 5 parts by weight of oil of vitriol in cast-iron pots (Fig. 25) to a temperature of 160° C. for an hour. The cast-iron pots employed, A, are about 2 feet wide and 2½ feet deep; they are cast half - closed at the top, the remaining half being covered by a semi-circular sheet of thick lead, Fig. 26, having a small opening to admit of the introduction of the chloranthracene, about 1 cwt. of chloranthracene forming the charge. The gases evolved during the reaction are conveyed to a scrubber by means of stoneware pipes fixed in a socket, B, cast on the top of the pot. (Three pots thus connected are shown in Fig. 27.) A small quantity of anthraquinone sublimes into these pipes, which is at times scraped out, washed, dried, and then mixed with the chloranthracene for use in other operations.

Great care must be taken to see first that the chloranthracene be sufficiently pure and dry, and also that the oil of vitriol is at its maximum strength, otherwise loss will result from the boiling over of the pots, and the formation of other products than disulpho-anthraquinonic acid. After the heat has been raised to 160° C. for about an hour, the vessel and contents are allowed to cool somewhat; and while still fluid and having the appearance of coal tar, it is ladled out into copper pails, the contents of which are poured into large rounds, fitted with wooden stirrers, holding about 1000 gallons. These rounds are half-filled with water and the washings of filters. Slaked lime is added till the liquor is neutral to test paper, and steam being introduced the liquid is, whilst being continuously stirred, brought to the boil, upon which a plug having been withdrawn, the thick liquid is run by means of wooden shoots on to the filters placed beneath the rounds.

The filters are formed with 3-inch deals, and are about 12 feet square and 2½ feet in depth. The bottom is covered with a layer of smooth bricks, supported by bricks placed edgeways and arranged in channels, so as to afford a free exit for the filtered liquor. Small pebbles, about the size of peas, are scattered over the bricks to the depth of about 1 inch, and over these a layer of sand 2 inches in thickness is spread. A coarse jute canvas is then thrown over the sand, which is secured in its place by slight wooden frames, the edges of the canvas being tacked to the sides of the filter.

At the centre, underneath the filter, is fixed a wrought-iron pipe to carry off the liquor. This pipe is connected with a cylindrical receiver of wrought iron, capable of containing about 1000 gallons, and exhausted by means of an air-pump. A second receiver is also connected with each filter, in order that whilst one is being emptied the other may be filling. A glass gauge is affixed to each receiver to indicate the state of the contents. When the receiver is full the vacuum is shut off, and air being admitted by a cock on the top of the apparatus, the liquor is run out into semicircular evaporating pans, which are from 20 to 30 feet long and 7 or 8 feet wide. These pans are formed of half-inch iron plates, flush-rivetted on the inside and jacketed outside, and are connected with the steam main. They are coated on the outside with felt and set in brickwork. Their tops are covered with wood-work, in the centre of which rises a wooden chimney carried through the roof of the building, by which the steam escapes into the air.

Fig. 25.



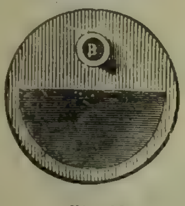
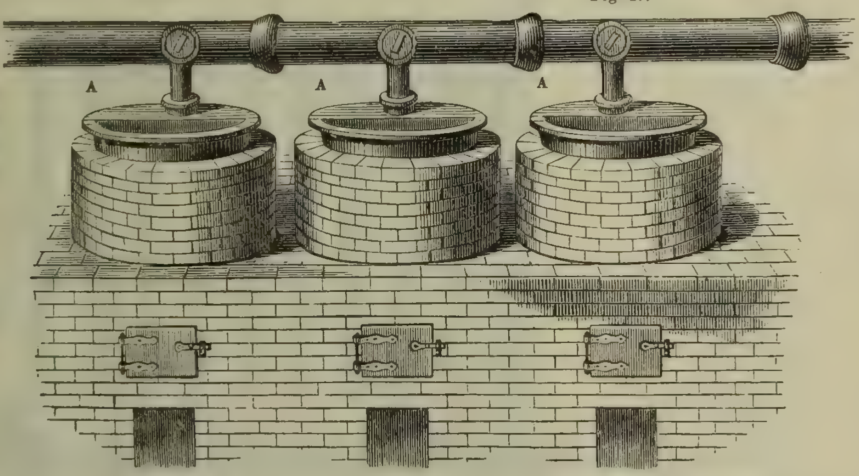


Fig. 26.

Fig. 27.



After the liquor from the receivers has run off into the pans the black mud left on the filter is taken up and boiled in the rounds with the weak washings of former operations. The liquid is filtered through the vacuum filters, and the filtrate is conducted into the receivers which contained the first liquors, the weak liquors being evaporated with the strong. The residue is again taken up into the rounds and boiled with water, the liquid as before being run into the filters, the weak liquors being conducted to receivers appropriated to them, of similar form and size to those already described. The operation of boiling the residues with water is repeated once or twice until the soluble calcic di-sulphanthraquinonate is washed out, the weak liquors being used as above. The liquors containing the calcic di-sulphanthraquinonate are then evaporated to about one-third of their volume, when sufficient soda crystals are added to precipitate the lime as carbonate, the sodium salt remaining in solution. When the calcium carbonate has settled the liquor is drawn off and evaporated in another pan of similar construction, until the liquid contains about 25 per cent. of dry sodium di-sulphanthraquinonate. The solution is then drawn off and stored in open cast-iron tanks, provided with a stopcock for the purpose of drawing off the contents when required.

The next operation of the manufacturer is the conversion of this salt into sodium alizarate.

About 6 cwts. of the liquor is put into a jacketed iron vessel heated by steam, and to this is added

3 cwts. of caustic soda, previously dissolved in a small quantity of water; the bulk is then made up to about 150 gallons. During the mixing the liquid thickens, and in that state is run into a strong wrought-iron vessel (Fig. 28) capable of bearing a pressure of 300 lbs. per square inch. Fig. 28 shows a drawing of the apparatus, which consists of ten upright tubes connected with a large horizontal tube:—A, pipe for discharging the contents of the tube; B, pipe used in charging the apparatus; C, stop valve closed during operation; D, cock for letting off superfluous steam; E, cock connected with the steam main. The front of the apparatus, showing the door, F, for cleaning out, is represented in Fig. 29. The mixture is heated in this vessel, which is set in an oven heated by flues to a temperature of about 160° Centigrade, a thermometer and pressure-gauge being used to regulate the temperature. This heat is continued from eight to twelve hours or more, the best result being obtained when the temperature is low and long continued. It is also advantageous to introduce a small quantity of chlorate of potash into the mixture before heating, as a reduction occurs occasionally within the vessel, anthraquinone or even anthracene being formed. In an early stage of this operation an intermediate product is formed, which becomes converted into alizarin by continued heating with the alkali. Samples are taken out at times, which are dissolved in water, and the alizarin precipitated by an acid. The filtered liquor is then rendered alkaline by potash or soda, and according to the diminution of the violet colour produced the finish of the operation is determined. The conversion being completed, a cock connected with the apparatus is opened, and the product is then forced by the pressure of the steam within the pan into an iron tank placed on the top floor of the building. As soon as the thick liquid is thus expelled the surplus steam is allowed to escape by opening a cock on the top of the apparatus. Boiling water is then admitted into the vessel, which dissolves all that may have adhered to the sides, and the steam being admitted, the washings are forced up into the tank containing the colour, which prevent the liquid from setting before it is precipitated. On the floor below this tank are placed wooden backs lined with lead, which are used for precipitating the alizarin from its alkaline solution. These tanks are half filled with dilute sulphuric acid, and while still hot the alkaline liquor is slowly added until the acid is completely neutralized, which is known by the alteration of colour which ensues as soon as an excess of the alkaline solution is added. During the precipitation large quantities of sulphurous acid gas are generated, which are conveyed by wooden flues into the open air. The liquid is continually stirred during the operation to prevent the tanks from frothing over. When the precipitation is complete the liquid presents a bright yellow colour, due to the particles of alizarin, which after standing a few hours settle down. The supernatant liquor having been drawn off, the tanks are filled up with water, and well boiled by means of a steam-pipe until the precipitate becomes more dense and easy to filter. The filters used for the alizarin are nearly of the same description as those used to filter off the calcium di-sulphanthraquinonate. They are provided with covers to prevent the introduction of dust, and calico is used in the place of the coarse canvas. A cleaner kind of filter without bricks is also used, which is constructed in the following manner:—Several lengths of wood 2 inches square, notched at intervals on the under side to allow of the free escape of the liquor, are placed on the floor of the filter at distances of about 1 foot apart. Over these is laid a flooring of inch boards pierced with numerous small holes, and over the flooring is stretched a piece of thick felt, such as is used for carpets; over the felt a sheet of calico is tacked to the sides of the filter, and secured in its place by slight wooden frames. These filters are connected

Fig. 28.

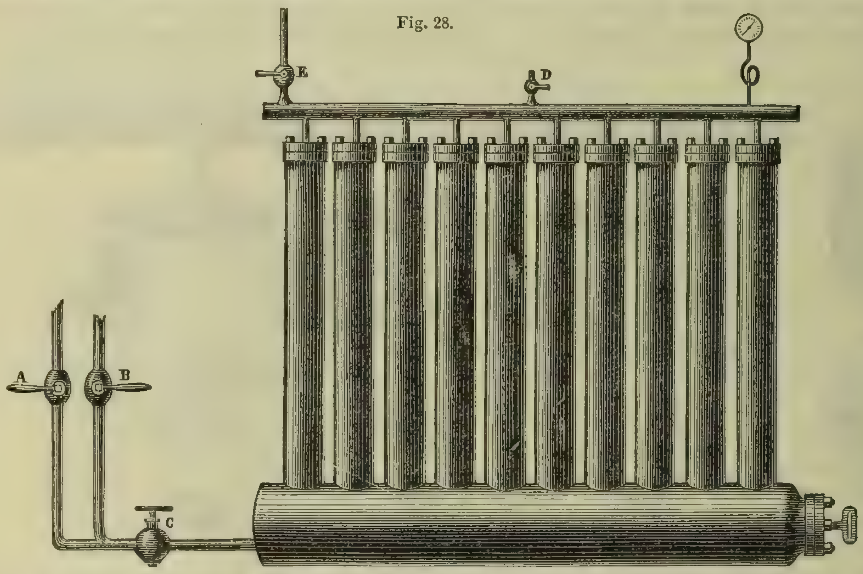


Fig. 29.

with an exhausted receiver in the same manner as those with brick bottoms.

The clear liquors being drawn through, the alizarin lying on the filters is washed with hot water, applied by an india-rubber hose, having a rose jet at its extremity, until all the soluble salts are removed. The liquors run from the receiver into a large tank lined with lead and there deposit any alizarin the hot water may have dissolved, which is afterwards collected and purified. When sufficiently washed the alizarin, now of a bright orange yellow colour, is removed from the filters into large oaken rounds, and well agitated, until it becomes a thick liquid. A sample is then taken out and tested for strength and colour in the following manner.

Ten grammes of the colour to be tested are shaken up with water, and made up to 400 cubic centimètres. 10 grammes of the standard colour are also made up to the same volume. Some glass beakers, each containing an equal quantity of distilled water, are placed in a copper water bath half filled with water. To these beakers are added different portions of the colour to be tested, one of the beakers being reserved for the standard colour, 10 cc. of which are introduced therein. A number of pieces of cloth mordanted in stripes with alumina and iron, and combinations of these two, are soaked in water, and a piece of equal size placed in each beaker. The vessel is then heated gradually over a gas lamp or sand bath for about an hour, until it comes to the boil, the pieces of cloth being well stirred during the heating. After the boiling point is reached, this temperature is kept up for about one half hour more, when the pieces of cloth are removed from the beakers, and well washed in distilled water. They are then soaped in a solution containing ½ oz. of soap to the gallon of distilled water, and in a few minutes are taken out, well washed, and dried. The pieces are then compared with the standard, and the quantity of water necessary to bring the colour to standard strength is found by calculation. After the addition of the water the colour is stirred well for about an hour, and is then ready to be drawn off into casks for use.

Although usually styled alizarin, the colour made by this process consists mainly of anthrapurpurin, with an admixture of only a small proportion of alizarin. It produces a much more orange shade with alumina mordants than alizarin, and is on that account much used for Turkey red dyeing. A much larger quantity of alizarin may be produced in the colour if only two parts of sulphuric acid are used in the place of four or five. As yet, however, this has not been done, on account of the loss which takes place during the combination, before the requisite temperature for the formation of a mon-acid anthraquinone is produced.

The progress of the operation during the melting may be judged by taking out samples from time to time, dissolving in water, adding sulphuric acid, and noticing the quantity of flakes thrown down. At first these are few, but as the action goes on the alizarin is formed, and the precipitate becomes larger.

Alizarin may be distinguished from oxyanthraquinone monosulphonic acid by its solubility in ether, the latter remaining undissolved when the liquid and precipitate are agitated with ether in a test tube. The crude alizarin precipitated by acids from the solution of the "melt" usually requires some purification before it is fit for use in dyeing. By washing with water, adhering acid, alkaline salts, &c., are removed, and also some of the oxyanthraquinone monosulphonic acid. Oxyanthraquinone and anthraquinone, however, are apt to be present, and to remove these the product is dissolved in dilute caustic soda ley (free from alumina, otherwise loss ensues from the production of alumina lake). After standing some hours the clear portion is run off, the last portions being filtered, and dilute sulphuric acid is then added in slight excess, so as to precipitate a purified alizarin. A better method is to add calcium chloride solution to the caustic soda alizarin solution, a calcium alizarin lake being thrown down, whilst oxyanthraquinone mostly remains in solution. The filtered and washed lake is then decomposed by hydrochloric acid, forming calcium chloride, alizarin being regenerated.

Auerbach purifies alizarin by dissolving the crude material in caustic soda, filtering, and passing carbon dioxide into the liquor. A mixture of alizarin and sodium alizarate is precipitated. This is then collected, washed, and treated with hydrochloric acid.

The precipitated alizarin is then washed on calico filters till the runnings are no longer acid, and allowed to drain thoroughly. The thick mass is then placed in a closed copper rotating drum, containing a stone or copper ball; the alizarin thus becomes very finely divided, the whole being converted into a thick paste, which has but little tendency to subsidence, an inconvenient phenomenon often exhibited by the crude product, and leading to want of uniformity in composition of the contents of each keg of paste made. This paste is then packed for the market in glass jars, wooden kegs, or zinc boxes. It usually contains 10 to 15 per cent. of dry alizarin. The shade varies slightly, some varieties having a yellow cast, which renders them more suitable for scarlets, others possessing a violet or lilac shade.

Simultaneously with artificial alizarin at least three other allied products are formed, viz:—

Oxyanthraquinone,....................	$C_{14}H_7O_2(OH)$.
Anthraflavic acid (Perkin),...........	$C_{14}H_6O_2(OH)_2$.
Anthrapurpurin (Perkin), isopurpurin (Auerbach),.....................	$C_{14}H_5O_2(OH)_3$.

The first of these products is probably formed from mono-substitution compounds of anthraquinone, produced during the manufacturing process. The second, as Perkin has shown, is isomeric with alizarin. The third body was supposed for some time to be identical with the purpurin of madder; but Perkin has recently shown that it is only isomeric therewith. Auerbach has also come to the same conclusion from his experiments.

A colouring matter of an orange tint has been prepared from anthracene; this is also an anthraquinone derivative, being diamido-anthraquinone,

$C_{14}H_6(NH_2)_2O_2$. BŒTTGER prepares this substance by acting on dinitro anthraquinone with reducing agents, such as sodium stannite, sodium or ammonium sulphydrate, sodium sulphide, &c., the action being analogous to that by which aniline is formed from nitrobenzol (*vide* article ANILINE),

$$C_{14}H_6(NO_2)_2O_2 + 6H_2 = 4H_2O + C_{14}H_6(NH_2)_2O_2.$$

From experiments made by AUERBACH, BŒTTGER, and PETERSEN, it seems very probable that this body may ultimately turn out to be the parent of a number of other dyestuffs.

SPRINGMUHL has extracted a blue colouring matter from the bye products of the manufacture of alizarin; as yet, however, this substance has not been subjected to much study, and has no commercial importance.

COBALT.—*Cobalt*, French; *kobalt*, German. Symbol Co. Atomic weight, 58·8; atomicity, 2, 3, and 6.

History.—This metal was not known until within comparatively recent times. It had been supposed, from the beautiful blue colour of specimens of ancient glass and enamel, such as the tiles of some Roman tesselated pavements, that it was known in very early times; but as cobalt has never been found in any of these, and since it has also been shown by GMELIN that a beautiful blue colour may be produced in glass by the presence of oxide of iron or oxide of copper (as, for example, the resplendent colours of many iron and glass-house slags), it appears most improbable that the ancients were acquainted, even empirically, with the property of cobalt to impart a blue colour to glass, or that they ever used any cobalt mineral for that purpose.

The Bohemian and Saxon miners, about the fourteenth or fifteenth century, seem to have been often disappointed in their efforts to obtain copper and other metals useful to them, finding in their stead a mineral then useless, and which often deluded them with the hope of valuable ore. They gave to the mineral the name of *kobalt*, comparing it to Kobalus, a supposed malicious sprite, which in their superstition they supposed to haunt the mines and destroy their works, giving them much annoyance; it appears even to have been customary to introduce into the church service a prayer for the protection of the miners from "*kobalts* and spirits."

In course of time it was discovered that this mineral imparted a fine blue colour to glass; and after having been used for this purpose for more than two centuries, it in 1733 attracted the attention of the celebrated Swedish chemist, BRANDT, who obtained from it a new "semi-metal," as he described it, to which he gave the name of *cobalt.*

LEHMANN in 1761 wrote a very complete account of this body, and the discovery of BRANDT was subsequently confirmed by BERGMAN about 1780. It has since been examined by TESSAERT (Ann. de Chim. xxviii. 101), by THÉNARD (ibid. xlii. 210), and by PROUT (ibid. lx. 260).

Natural History.—Cobalt occurs in nature usually in association with the ores of nickel, copper, and bismuth, and also occasionally with manganese. It is found in the metallic state in some specimens of meteoric iron, varying in quantity from 2 to 0· per cent.

The following are the most important minerals:—

Smaltine.—Arsenical cobalt or tin white cobalt is one of the most plentiful of the cobalt minerals, and occurs chiefly associated with the ores of bismuth, nickel, and copper, at Schneeberg in Saxony, at Joachimsthal in Bohemia, and at Wittichen, Siegen, Saalfeld, and Mansfeld. It is the most frequently-occurring English mineral, and is found in this country at Huel Sparnon, near Redruth, and also at Dolcoath and Herland, all in Cornwall.

It is of a tin-white colour, inclining when massive to steel-grey, and occurs in crystals of the cubic system, which are frequently fissured in all directions, and also in reticulated, botryoidal, stalactitic, and amorphous forms. At Riechelsdorf, in Hesse, its veins are inclosed in cupriferous shale, and the net-like variety from Joachimsthal is frequently imbedded in calcareous spar.

Its composition is that of cobalt arsenide, $CoAs_2$, in which, however, the cobalt is often more or less replaced by iron, nickel, and copper. The following analyses are by STROMEYER (*a*) and by VARRENTRAP (*b*):—

	(*a*) Riechelsdorf.			(*b*) Tunaberg.	
Cobalt, ...	20·31	per cent.	....	23·44	per cent.
Arsenic, ...	74·21	"	....	69·46	"
Iron, ...	3·42	"	....	4·95	"
Copper, ...	·15	"	....	—	"
Sulphur, ...	·88	"	....	·90	"

Before the blow-pipe it emits copious arsenical fumes, and gives a blue bead with borax or microcosmic salt. It may be distinguished from cobaltine by the absence of any distinct cleavage. It dissolves in nitric acid, usually giving a pink solution.

Cobaltine.—Cobalt glance, or bright white cobalt, is the next, and perhaps the most important mineral, since it is this that forms the bulk of the cobalt ores of commerce.

It is met with, in large distinctly-pronounced crystals belonging to the cubic system, at Tunaberg and Hakansbö, in Sweden, and at Skutterrud in Norway. It occurs abundantly in mica slate at Wehna in Sweden, less frequently at Querbach in Silesia, and also in the vicinity of St. Just and St. Austell in Cornwall. It may be distinguished from smaltine by its inferior specific gravity and reddish hue; also by its lamellar structure, its more distinct cleavage, and by its requiring considerably greater heat to drive off the arsenic. The colour is silver or yellowish-white, tinged with red.

Its composition is that of a combined arsenide and sulphide of cobalt, CoAsS. The following are analyses of it by STROMEYER (*a*) and KLAPROTH (*b* and *c*):—

	(*a*) SKUTTERUD.	(*b*) TUNABERG.	(*c*) TUNABERG.
	Per Cent.	Per Cent.	Per Cent.
Cobalt, ...	33·10	36·66	44·00
Arsenic, ...	43·47	49·00	55·00
Sulphur, ...	20·08	6·66	·50
Iron, ...	3·23	5·66	—
Deficiency, ...	·12	2·02	·50

Erythrite, or *Cobalt Bloom*, is a mineral usually found with the above, and probably a product of their oxidation under the influence of air and water. It occurs as peach-coloured incrustations, giving a green streak, and it has the composition of a hydrated arseniate of cobalt, $Co_3As_2O_8.8H_2O$, and is found abundantly at Schneeberg, Saalfeld, and Riechelsdorf.

Pyrolusite, the black oxide of manganese, is often found to contain about 5 per cent. of cobalt, probably as peroxide.

Skutterudite, a sesquiarsenide of cobalt, Co_2As_3, has been found at Skutterud, in the parish of Modum, Norway, and analyzed by Scheerer and Wöhler.

Mispickel, the ordinary arsenical pyrites, sometimes contains upwards of 2 per cent. of cobalt.

Cobalt pyrites, Co_2S_3, also occurs in grey octohedra.

Nearly all the minerals of cobalt occur in crystalline slates or other metamorphic rocks, either in embedded crystals reticulated or finely dispersed: and the value of the ores varies extremely, and not only depends upon the percentage amount of cobalt, but on their freedom from other metals, excepting nickel, and the presence of the latter in sufficient quantity to make its separation remunerative.

Metallurgy.—This metal is never used in the arts in the metallic state, so that its metallurgy is completely confined to laboratory processes.

To obtain it, the oxide obtained by any of the processes given further on is first purified. It is dissolved in nitric acid for this purpose, and the cobalt separated by addition of nitrite of potassium solution to the neutralized solution of cobalt. Upon allowing to stand a yellow precipitate settles, which, after being washed, is dissolved in acid, and the cobalt precipitated as oxide by addition of an alkali, or as oxalate by oxalate of ammonium.

The purified oxide thus obtained is dried and mixed into a paste with oil, and inclosed in a charcoal lined plumbago crucible, which is covered, well luted, and then strongly heated in a forge fire. The oxide is thus reduced, and the metal fuses to a button at the bottom of the crucible. This button is a carbide of cobalt analogous to cast iron.

Chemically pure cobalt may be obtained from purpureo-cobaltic chloride, a compound ammonium salt, which is easily obtained pure. It is first ignited, and the cobalt chloride which then remains is heated to redness in a current of hydrogen.

Ignition of the oxalate in a well-covered crucible lined with lime, also affords a very ready means of obtaining this metal in a pure state. To obtain it fused, however, it must be heated to the highest possible temperature attainable by a forge fire.

Properties.—Pure cobalt is of a grey colour with a shade of red, and is by no means brilliant. Its texture varies according to the temperature employed in fusing it; sometimes it is composed of plates, sometimes of small fibres adhering to each other. It is very hard, and nearly as infusible as iron. Like iron it is attracted by the magnet at the ordinary temperature, but loses this property upon moderate heating. It can be magnetised permanently, and Pouillet states that this magnetism is not destroyed by a red heat. It cannot be fused in presence of charcoal without taking up some of the latter, and forming a compound analogous to cast iron.

By reducing the oxalate in a crucible lined with lime, Deville states that he obtained a metal which, when drawn into wire, was so remarkably tenacious as to be twice as strong as a similar iron wire.

At the ordinary temperature cobalt is permanent in the air, acquiring only a superficial tarnish, and it is also unacted on by water. But if heated to redness in the air it absorbs oxygen, and becomes converted into the oxide, the powder of which is at first blue, but becomes gradually deeper in colour and at last black, being then the peroxide, Co_2O_3, or the protosesquioxide, Co_3O_4, according to the temperature employed.

If very strongly heated the metal burns in the air with a reddish flame, and at a red heat it decomposes the vapour of water.

Hydrochloric and dilute sulphuric acids slowly dissolve it, forming the chloride and sulphate respectively. Nitric acid acts violently upon it, forming the nitrate.

The specific gravity of the metal is 7·834 (Turner), but has been very variously stated, and its specific heat is ·10696 (Regnault).

Alloys.—When alloyed with gold a dark yellow mass is obtained, which is very brittle when the cobalt is present in considerable proportion; but even with less than 2 per cent. of cobalt the resulting alloy is still brittle (Hatchett).

Silver does not alloy with cobalt, but when the two are fused together a layer of cobalt is obtained containing a little silver, and also one of silver rendered brittle by the presence of a small quantity of cobalt.

With zinc, lead, and bismuth, cobalt does not exhibit any tendency to alloy; but with iron a hard somewhat tough alloy results, and with tin a ductile metal is obtained, which has a violet tinge.

With platinum a fusible alloy is obtained, and with mercury a silver white amalgam.

Oxides.—There are two well-known basic oxides of cobalt, the protoxide, CoO, and the peroxide or sesquioxide, Co_2O_3. The protosesquioxide, Co_3O_4, is also a very definite body. It is here worthy of note that these oxides present a singular analogy to the oxides of iron, and this analogy is noticeable in many other of the compounds, properties, and reactions of this metal.

The protoxide is obtained by igniting the carbonate out of contact with the air in a well luted crucible, when it is obtained as a greenish grey powder, which dissolves readily in acids, forming the common cobaltous salts. All the definite salts of cobalt correspond to this oxide.

By addition of potash to a solution of any of these salts, a blue precipitate of a basic salt is thrown down, which, if protected from the air, changes immediately upon heating, or upon standing for some time, to a dingy red colour, becoming converted into the hydrated protoxide. But if exposed to the air the blue precipitate absorbs oxygen and becomes slowly converted into the peroxide, acquiring a greenish grey colour. The rose-coloured hydrated protoxide also absorbs oxygen rapidly upon admission of air. The precipitate obstinately retains portions of alkali.

The sesquioxide of cobalt is obtained by passing chlorine through a solution in which the hydrated protoxide is suspended. Cobalt chloride is formed, and the peroxide remains as a black powder.

$$3CoH_2O_2 + Cl_2 = CoCl_2 + Co_2O_3 + 3H_2O.$$

It can also be obtained by adding solution of bleaching powder to a solution of a salt of cobalt.

There are three other oxides of cobalt intermediate between the protoxide and peroxide, viz., Co_3O_4, Co_6O_7, and Co_8O_9; but with the exception of the first one, which is a definite body obtained by ignition of cobaltous nitrate, they are unimportant.

Commercial Oxide of Cobalt.—For commercial purposes the oxide is obtained by one or other of the following processes:—

1. The speiss obtained by smelting the ore is first powdered, dissolved in nitric acid, or hydrochloric or diluted sulphuric acid. The solution is evaporated to a small volume to separate the bulk of the arsenic as arsenious acid, and then diluted and decanted from that substance. It has next to be treated (being still acid) with sulphuretted hydrogen, as long as any precipitate is thrown down. After filtration the excess of sulphuretted hydrogen is expelled by boiling, and carbonate of soda added while the liquid is still warm. The cobalt, nickel, and iron thus precipitated are digested (after being well washed) in a solution of oxalic acid added in excess. The ferric oxide is dissolved by the oxalic acid, while the oxalates of nickel and cobalt are left insoluble. These are then well washed, dissolved by digestion with warm aqueous ammonia, and the solution allowed to stand exposed to the air for some days. The greater part of the oxalate of cobalt is retained in solution as the ammonia evaporates, but the whole of the nickel is precipitated and carries with it a little of the cobalt, which, however, may be recovered by redissolving the precipitate in ammonia and repeating the exposure. The ammoniacal solution of oxalate of cobalt thus obtained is evaporated to dryness, and ignited in the air to obtain the oxide. This process, devised by LAUGIER, gives the oxide almost entirely pure.

2. BERTHIER, to shorten the process of passing sulphuretted hydrogen in the above process, recommends that carbonate of potash be added to the liquid in small successive quantities as long as the precipitate consists of iron. At first it is white from presence of arseniate of iron, and if there be not enough iron in solution to precipitate all the arsenic in this form, some solution of ferric chloride must be added to slight excess. By careful addition of the carbonate of potash the iron must be exactly removed.

The bismuth and copper are then removed by passing sulphuretted hydrogen through the acidified liquid, this process now requiring much less time; and the liquid, which contains the nickel and cobalt free from iron, is treated for their separation by any of the methods given.

3. Another process recommended by LIEBIG for the treatment of arsenical ores, depends upon the stability of the sulphate of cobalt. The finely divided and well roasted ore is added in small portions to three times its weight of bisulphate of potash, fused in an earthen crucible or iron pot. The pasty mass thus obtained is then strongly heated till fumes of sulphuric acid are no longer given off, and then it is poured out. When cool it is broken up and boiled with water, and the solution, after removal of the insoluble arseniate of iron and nickel oxide, is treated with sulphuretted hydrogen to separate copper, bismuth, and antimony. The precipitate is filtered off, and then carbonate of soda added to the filtrate to precipitate the cobalt. This precipitate, upon ignition in the air, gives oxide of cobalt; but it is liable to be contaminated with nickel, because the sulphate of nickel is not easily decomposed, and in presence of sulphate of potash still less easily. Care should be taken that there is an excess of iron present during the fusion, over that required to combine with all the arsenic, otherwise arseniate of cobalt will be formed, and cause loss of that metal by not dissolving when the mass is treated with water.

4. WÖHLER's method for obtaining cobalt from arsenical ores consists in fusing the powdered ore with six times its weight of a mixture of carbonate of potash or soda and sulphur in equal quantities. The temperature is not raised high enough to fuse the sulphide of cobalt produced. The arsenic and sulphur combine with the potassium, forming a soluble sulpharsenite which, on being treated subsequently with water, is washed out. After this washing the residue is again fused with the mixture and again exhausted with water, to further remove the arsenic, and the product thus obtained is dissolved in nitro-hydrochloric acid and treated with sulphuretted hydrogen, which removes copper, bismuth, and any remaining arsenic. Then it is filtered, and the filtered liquid treated for the separation of the cobalt from the accompanying iron, nickel, &c.

5. WACKENRODER gives a process for the preparation of cobalt from cobaltiferous manganese. The ore is dissolved in hydrochloric acid and sulphuretted hydrogen passed through the solution to precipitate copper and other metals; the liquid is then precipitated with an alkaline sulphide, and the precipitate digested with cold dilute hydrochloric acid, which dissolves the sulphides of iron, zinc, and manganese, but leaves the cobalt and nickel.

Manufacture. — On a large scale, the process adopted for the manufacture of cobalt oxide is usually a modification of that recommended by BERTHIER. The finely powdered and well roasted cobalt speiss is dissolved in strong hydrochloric acid, and the iron and arsenic precipitated together, as described in 2, by the gradual addition of milk of lime. The liquid is run off from the precipitate, treated with sulphuretted hydrogen, and again run off the precipitated sulphides, and the cobalt separated from it by the careful addition of solution of bleaching powder.

The oxide possesses the property of imparting an intense azure blue colour to glass and most vitrifiable bodies, and that to so great an extent that pure white glass is rendered sensibly blue by the addition of $\frac{1}{1000}$th part of the oxide, while $\frac{1}{20000}$th part communicates a perceptible azure tint.

It is in consequence of this property that the oxide is used in the potteries, and by enamellers and glassmakers, as a blue pigment for their glazes. For this purpose they mix it in proportions varying according to the tint required with a vitrifiable flux, and apply it to their wares mixed with some adhesive material. A formula for a blue, known in the potteries as china blue or royal smalts, is—

Oxide of cobalt	1 part.
Pearl ash (free from iron),	1 "
White felspar (ground),	8 "

When the painted articles are subjected to a heat strong enough, the flux melts and dissolves the oxide of cobalt, acquiring a blue colour.

A black colour, used by enamel painters, is obtained by calcining oxide of cobalt with borax, and mixing the black mass thus obtained with very finely powdered black oxide of manganese. When fused the mass is deep black. A mixture of manganese and cobalt oxides is sometimes used by glass makers to make a good black glass.

Principal Compounds.—Cobalt forms two classes of compounds corresponding to the two basic oxides, namely, cobaltous compounds, corresponding to CoO, and cobaltic, corresponding to Co_2O_3. Of these the cobaltous compounds are by far the most stable, and also most numerous, and to this class belong all the ordinary salts of cobalt.

Cobaltous Salts are red when containing water of hydration, but blue when anhydrous. Their solutions are of a light red colour when not too concentrated, and this colour they exhibit even when considerably diluted. They redden litmus paper. With the exception of the sulphate they are all decomposed at a moderate red heat.

The chloride is formed when cobalt is heated to burning in chlorine gas. The anhydrous salt thus obtained forms blue crystalline pearly scales, which exhibit but little tendency to dissolve in water and are greasy to the touch. They absorb water from the air, changing to red, and then dissolve readily. The chloride may also be obtained, crystallized in rose red hydrated crystals, by dissolving the metal or any oxide in hydrochloric acid and evaporating the solution. These crystals are not deliquescent, and when heated partially decompose, giving off hydrochloric acid and leaving a greenish blue mass, supposed by Berzelius to be an oxy-chloride; and this upon further heating yields a sublimate of the anhydrous chloride, and leaves an oxidized residue.

When very concentrated, the colour of cobalt chloride solution is blue; but when more dilute it is rose red, which upon heating or upon addition of concentrated hydrochloric acid, absolute alcohol, or any dehydrating agent, changes to blue. In dilute solutions the colour is a delicate rose pink, and it is perceptible even when the solution is very dilute.

Sympathetic Inks.—The dilute solution of the chloride forms a "sympathetic ink." Writing upon a piece of white paper with it the characters are practically invisible, but upon applying heat to the paper they appear of an intense blue colour, due to the production of the anhydrous salt, or an isomeric modification. Upon cooling the writing gradually fades, from the reproduction of the original hydrated salt. The heat applied must not be too great, or the salt will decompose and appear of a black colour, which will not disappear again.

If desired, the colour can be modified. Thus, addition of a small quantity of an iron or nickel salt will cause the writing to appear green instead of blue. Zinc sulphate gives a red colour, and copper sulphate a yellow. By using suitable solutions what are called magic landscapes are produced, which are invisible, but upon applying a gentle heat appear in their proper colours.

The bromide and iodide give analogous chromatic phenomena.

Detection.—Cobalt in solution is detected by the following reactions:—

Sulphuretted hydrogen in acid solutions produces no precipitate.

Sulphide of ammonium in alkaline or neutral solutions gives a black precipitate, the formation of which is much facilitated by the addition of chloride of ammonium. The precipitate is only dissolved with great difficulty by hydrochloric acid, but easily by warm nitro-hydrochloric.

Potash and soda precipitate blue basic salts, which upon boiling turn pale red or become discoloured by absorption of oxygen. The precipitate is insoluble in excess, but carbonate of ammonia gives a violet solution either with the basic salt or the red hydrate.

Ammonia produces a blue basic precipitate in excess, which readily dissolves, forming a red solution, which on exposure to the air becomes violet.

Ferrocyanide of potassium precipitates the green cobalt salt, which is insoluble in hydrochloric acid.

Cyanide of potassium gives a brownish white precipitate of cobaltous cyanide, easily soluble in excess. From this solution acids precipitate it again. When, however, the solution of cyanide is boiled after addition of a drop or two of hydrochloric acid (to liberate prussic acid), the cyanide of cobalt is converted into cobalticyanide of potassium. Addition of acid does not now produce a precipitate.

Tartaric (or citric) acid and then ammonia in excess gives a solution which on addition of ferricyanide of potassium turns deep yellowish red, or when very dilute, rose coloured.

Carbonate of baryta does not precipitate cobalt, but if bromine water in excess be first added, the whole of the cobalt is precipitated as peroxide after standing for some time.

Nitrite of potash added in excess to the solution rendered acid with acetic acid produces upon standing in a warm place a yellow crystalline precipitate; quickly in concentrated, only slowly in dilute solutions. This precipitate is soluble in water, but not in solutions of potassium salts or in alcohol. This is a very characteristic reaction.

In the borax bead compounds of cobalt dissolve to a clear deep azure blue glass, either in the inner or outer blowpipe flame. This reaction is very delicate and characteristic. With too much cobalt the colour approaches black.

With carbonate of soda on charcoal before the blowpipe, cobalt is reduced to the metallic state. The solution of the globules in nitric acid is pink.

Separation.—The separation of cobalt from other metals presents considerable difficulty, particularly from nickel, with which it is not only closely allied, but also often associated.

Cobalt is found with iron, nickel, manganese, zinc, and other members of this group, in the precipitate produced in an alkaline solution, which has previously been treated in an acid condition with sulphuretted hydrogen, which will have removed any copper, tin, bismuth, arsenic, &c., that might have been present.

The precipitate produced by the sulphide of ammonium, which will be black if it contain cobalt (or nickel or iron), is dissolved in warm nitro-hydrochloric acid, and freed from sulphuric acid by addition of barium chloride. It is then neutralized and digested with carbonate of barium. The aluminic, ferric, and chromic oxides thus precipitated will carry down traces of nickel and cobalt if a sufficient quantity of ammonium chloride be not added. From the filtrate the cobalt is precipitated with nitrite of potassium. To perform this operation it is necessary first to evaporate the solution to a small bulk, and neutralize it with caustic potash. A solution of nitrite of potassium having been neutralized, or rendered slightly acid by addition of acetic acid, is then added to the cobalt solution and the whole allowed to stand for two days, during which a yellow precipitate separates. Any precipitate that appears at once is removed by dropping in acetic acid. The yellow compound, the potassio-nitrite of cobalt, is then filtered off, and to the filtrate more nitrite of potassium is added, to see if any further quantity of the cobalt precipitate is produced. FRESENIUS and H. ROSE state that this is by far the most exact method of separating cobalt.

Another method that may be adopted, when no manganese is present, is to take the solution filtered from the precipitate produced by barium carbonate, and to add to it an excess of bromine water (or else saturate it with chlorine). It must be very dilute, not more than a gramme of cobalt to 300 c.c. of water. Some freshly precipitated carbonate of barium is then added, and upon standing the whole of the cobalt is separated as peroxide, and may be estimated by solution in hydrochloric acid and proceeding as below, after separating the barium by addition of sulphuric acid. Traces of cobalt are usually left behind with the nickel.

Estimation.—When a salt of cobalt is precipitated with potash the precipitate invariably carries with it a portion of alkali, from which it cannot be freed either by boiling or washing. Hence it is impossible to use this precipitate for estimating cobalt. For even if it be reduced in a current of hydrogen to the metallic state, the alkali cannot even then be removed by boiling with water (FRESENIUS). When, also, the sulphide of cobalt is ignited with excess of sulphur in a current of hydrogen, the residue has a variable composition, according to the temperature employed.

But, on the other hand, the sulphate is a very stable salt, not easily decomposed by heat, and the metal itself is easily obtained by ignition of the oxide or chloride in a current of hydrogen. The residue left on ignition of the nitrate is also a very definite compound, corresponding to the formula Co_3O_4.

Hence the most satisfactory methods for the estimation of cobalt are the three following:—

1. Having separated the cobalt from other metals, and having it in solution as nitrate or chloride, evaporate the solution to dryness and ignite the residue in a stream of hydrogen to a very intense heat, and after cooling in the gas weigh the metal thus produced. In the case of the nitrate, when no other acid is present, the ignited residue may be weighed itself, and the cobalt calculated from the formula Co_3O_4.

2. Precipitate the cobalt as sulphide by means of sulphide of ammonium, taking care that a considerable proportion of ammonium chloride be present, otherwise the precipitation is imperfect; and also that the precipitate be washed with water containing sulphide of ammonium, and, at first, chloride as well. Dissolve the precipitate in nitro-hydrochloric acid, and evaporate to dryness in a porcelain dish, with addition of sulphuric acid. The sulphate thus obtained may be removed to a platina crucible and weighed after gentle ignition.

3. Finally, there remains the estimation of cobalt as nitrite of cobalt and potassium. The precipitate obtained, as described under the separation, is transferred to a weighed filter and washed with a 10 per cent. solution of acetate of potassium, the last portions of which are displaced by using alcohol of 80 per cent. strength. The precipitate is dried at 100° C. and weighed. It has the composition $K_3Co5NO_3.H_2O$, corresponding to 13·64 per cent. of metallic cobalt.

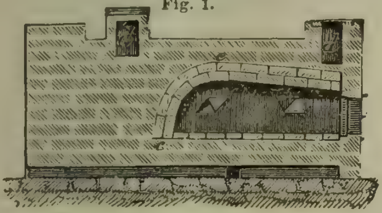
GIBBS and GENTH recommend that the precipitated nitrite be ignited, and the residue treated with sulphuric acid and again ignited. A mixture is thus obtained corresponding to the formula $2CoSO_4.3K_2SO_4$. This is more satisfactory to weigh than the potassio-nitrite itself.

SMALT.—Smalt is a blue pigment very extensively used in the arts, consisting of potash-glass coloured with oxide of cobalt, and it is produced by fusing properly prepared cobalt ore with materials to form a suitable glass.

Treatment of Ore.—Arsenical cobalt ores are employed for the manufacture of smalt, and they first undergo a preliminary sorting by hand, by which the grossly impure portions are rejected. The selected ore is then powdered in a stamping-mill, and the lighter siliceous and earthy parts removed by washing. This treatment, however, does not separate the metallic impurities from the cobalt, so that it still contains the nickel, the antimony, &c., with which it existed in the matrix. But when bismuth is present it is first removed from the ore, before powdering, by liquation in iron tubes or retorts. (See Bismuth.) Now these metallic impurities exercise a very hurtful influence upon the colour of the smalt, so that the next object in the treatment of the ore is to remove them.

Roasting.—This is effected by roasting the ores in a reverberatory furnace, with free access of air. The ores, the composition of which is, as before explained, chiefly arsenide and sulphide of cobalt, nickel, copper, and other metals, are oxidized by this treatment. The sulphur burns, forming sulphurous acid, which escapes, while the cobalt and other metals become partially converted into oxides; at the same time the arsenic also oxidizes to arsenious acid, which volatilizes and is carried away by the draught. The condensation of this arsenious acid must be effected in the process. Accordingly the manufacture is mostly pursued in winter, in order that the external cold may facilitate the operation, and the furnace employed is so constructed as to collect this volatile and poisonous product. Figures 1 and 2 represent this furnace.

Fig. 1.



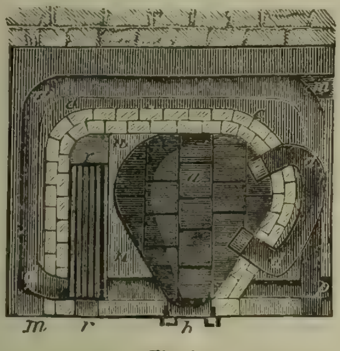


Fig. 2.

The arch, *c c*, and the sole, *a*, of the roasting-hearth are formed of fire-stone. From 3 cwts. to 5 cwts. of "schlich" (pasty ore) are introduced by the roasting door, *b*, and serve for one operation; they are spread out in a uniform layer 5 or 6 inches in thickness, and this is then exposed to the flame of a fire on the grate, *r*. The flame passes over the fire-bridge, *n n*, and escapes with the volatile products through the flues, *o o*, into the common flues, *d d*, which encircle the fireplace. The orifices, *m m*, of these flues are only intended for the purpose of cleaning, and are usually closed; through the opening, *p*, on the contrary, the smoke enters a long smooth gallery (*poison gallery*), or a broad chamber sufficiently wide to impede the velocity of the draught and allow the arsenious acid time to collect and deposit.

Now, if we suppose the ore to contain no other metal than cobalt, it would evidently be most advantageous to carry the roasting to the utmost limit of oxidation, otherwise the unchanged sulphide and arsenide of the metal would be decomposed in the subsequent fusion, at the expense of a portion of the alkali, into sulphide of potassium and oxide of cobalt, or would subside as a cobalt speiss, causing loss of the metal in either case.

But by so dealing with the impure ores usually worked, nickel, copper, &c., would be converted into oxide, which by entering the smalt would spoil the colour, the nickel communicating a hyacinthine, the copper a red or green tint. The presence of some iron, however, would be of but slight importance, since it is deprived of colouring power by the addition of arsenic in the subsequent fusion, while upon nickel, zinc, and copper, the arsenic exerts no influence.

Hence, in practice, the roasting is not carried beyond a certain point, at which sufficient arsenic is left behind to combine with all the nickel; and, on the other hand, the oxygen absorbed is insufficient to completely oxidize all the metals. Consequently in the fusion those metals that have the most powerful affinity for oxygen, viz., cobalt and iron, will retain it persistently, while the others, copper, silver, and bismuth, will separate as a metallic regulus, and the nickel will combine with the arsenic, for which it has so great an affinity, and separate as a nickel speiss. Both of these products will be found under the layer of blue glass. If the roasting is continued for too short a period, a portion of the cobalt will remain unoxidized, and pass with the other metals into the speiss, when a loss of colouring matter will result: a *small* amount of cobalt in the speiss is, on the contrary, a good sign, indicating that the roasting has been sufficiently advanced, and yet that enough arsenic has been left to combine with the nickel, for which it has a stronger affinity than for cobalt. Arsenide of cobalt and oxide of nickel are mutually decomposed by fusion into oxide of cobalt and arsenide of nickel. Even with the utmost care some oxide of zinc will pertinaciously adhere to the cobalt, when it will communicate a greenish tinge to the glass.

As before mentioned, when the ores contain much bismuth, as is the case with those of the Erzgebirge, the greater part is extracted before they are employed in the smalt works, and the remainder is found below the speiss as the lowermost layer in the pots.

Fusion.—When the powdered ore, or "schlich," as it is called, has been roasted to the above-mentioned point, which is ascertained by observing when the deepest tinted glass is produced, in a test fusion on a small scale, it is then ready for making the blue glass.

Experience has shown the manufacturers that the presence of lime, alumina, and other earths, impairs the colour by diminishing its lustre and purity, and the fineness of the tint is still more damaged by soda. Hence, in selecting their fluxes, they are guided by these considerations, and fuse the prepared ore with addition only of potash and silica, both as pure as possible.

The silica is always used in the form of quartz, but is submitted to previous mechanical purification. For this purpose the quartz is heated to redness, and then disintegrated by quenching in water; it is then pulverized in a stamping mill, and the meal washed, suspended in water, and the fine powder allowed to subside. The lighter earthy and ferruginous particles remain longer in suspension, and can be poured off, and by repeating the process pure quartz-meal is at length obtained, which, when dried and heated to redness, is technically called *sand*.

In buying the carbonate of potash (pot ashes or pearl ash of commerce) great care is exercised in selecting such as shall not, as often is the case, contain sand, sulphate of magnesium, chloride of sodium, or sulphate of potash, and of course the usual tests of its alkalimetric strength and amount of moisture are made. Since it absorbs moisture from the air it is necessary to calcine it pretty strongly before using it, chiefly in order to facilitate its being well mixed with the other materials.

The mixture of the roasted ore with quartz and potassa is carefully conducted in wooden tanks, with the addition of white arsenic, which is essential on account of the iron in the ingredients; the arsenic is used in the form of powder, as it collects in the poison galleries, and with it a small portion of oxide of cobalt is recovered, which is mechanically carried over by the draught.

The proportions of the ingredients vary extremely, both with the richness of the ore and also with its quality, as regards siliceous and earthy matter, as well as with the depth of tint required. The depth of tint is also influenced, as before hinted, by other things than the amount of cobalt present. Thus lime and alumina, if present in the ore, will materially lessen the colour and degrade its purity. The difficulty of obtaining a uniform and constant blue will be evident from these facts, as it must entirely depend upon the nature of the ingredients; and these are subject to change in every consecutive roasting. As a constant quantity of potassa is always employed in the smalt works, proportionate to the sum of the other constituents of the mixture, viz., one-third the weight of the ore and sand together, the only question that remains to be settled is the relative proportion of ore and quartz.

This is decided by a repetition of the manufacturing process on a small scale. A small quantity of the roasted ore is fused with what is thought to be a sufficient quantity of the quartz meal and potash to produce the required tint, and the resulting glass observed carefully as to whether it is under or over coloured.

A series of definite tints, usually three, can thus be kept constantly on hand, and from these any desired tint can easily be obtained by mixing them in suitable proportions. A complete set of all the gradations of colour producible by the constituents is requisite for this purpose, and also a series of specimens of all the tints required in commerce. The desired colour is only obtained by accurately mixing the tints in the proper proportions, and hence they are always weighed in the dry state and never measured.

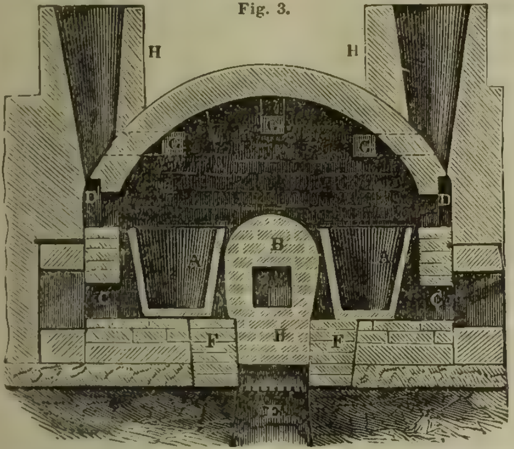
The operation of fusion is conducted in crucibles or pots, which are made of very refractory clay, containing no lime, and mixed with half its weight of dressed clay or cement. The mixture is well kneaded with water in a wooden trough, and the pots moulded, and then allowed to dry in the air. Afterwards they are very gradually heated to redness in a vaulted furnace, like a baker's oven, containing six crucibles at a time. If made too wet the pots crack on drying, and they split if they have not been thoroughly dried in the air. The best method of moulding them consists in beating the clay round a circular core, inclosed in a hollow cylinder, separated from the core by a distance equal to the thickness intended to be given to the crucible; the clay is heaped up gradually in small portions, and in the most uniform manner. The pots are a little conical, the larger circumference being at the upper part. They are 18 inches in diameter at top, 14 at bottom, and have a thickness of 2 inches. When they have been sufficiently exposed to the air, they are introduced into the furnace, and left there for from five to six days, during which the temperature is gradually raised to whiteness. Each pot is capable of holding about 84 lbs. of the mixture, and generally lasts seven or eight months.

The furnace in which the fusion is performed is similar to an ordinary glass oven; the separation of the speiss is the only essential difference in the process, and this gives rise to certain modifications in the construction of the furnaces, which are either circular, as at Schneeberg in Saxony, and Querbach in Silesia; or sometimes rectangular, as at Schwarzenfels in Hesse. They are adapted either for coal or wood. This will be more readily understood by reference to Fig. 3, which represents a German smalt furnace.

B is one of the openings for the insertion of the pots, which after this has been effected is walled up; the pots, A A, are pierced at the side with an orifice—speiss-hole—over against the *knee-hole*, C, for the withdrawal of the speiss. Through this opening the speiss and waste-glass are removed from the furnace, and the aperture is closed during the fusion. The working hole, D, is situated directly above, and serves for introducing and removing the ingredients and the glass. The flame is kindled on the grate, E, enters the furnace at F F, and passes out through the holes, G G G, which are in connection with the short chimney. Each pot, as before mentioned, holds about 84 lbs. of material, which is introduced by means of iron ladles furnished with long handles.

New pots are first filled with eschel, so as to coat the interior with a glaze. In the course of eight hours the mixture enters into fusion, the workman occasionally stirring it up with a red-hot iron to break up the crust which forms on the surface. It is only when the molten mass is at a white heat that a chemical combination of the materials is effected; at this point the stirring must cease, and the heat be sustained, in order to aid the settling of the speiss.

Fig. 3.



Every time that the pots are recharged a depression of the temperature occurs, and it usually takes from an hour to an hour and a half to bring them back to whiteness. The furnace is said to work well if the pots glow, and the flame comes out briskly to the openings of the vault.

When the glass adheres to the workman's rod, and admits of being drawn into threads, or when it is homogeneous, it is ready for the next operation, which consists in ladling it out into a vessel full of water, kept cool by being repeatedly stirred. The vitrified mass falling in a molten state into water, becomes granular and easy to pulverize. If the potassa salt employed is pure, the scum, which is known as *glass-gall* or *sandiver*—impure sulphate of potassium—is not formed, but there is usually a portion to be skimmed off. When the cobalt contains nickel, an arsenide of this metal is produced, united with different metallic substances, which is deposited in the crucibles. A part remains even in suspension, so that in the Schneeberg works, when a pot is half emptied, they always expect to meet with globules of this alloy of cobalt, nickel, iron, arsenic, bismuth, and sometimes silver, which is known under the name of *speiss*. Every time that the workman draws off the blue glass, he allows this matter to deposit in his ladle, and before throwing the glass into water, he makes the speiss fall into an iron basin provided for its reception.

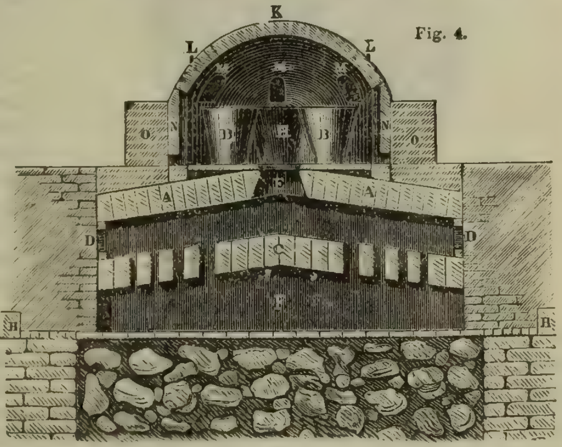
At Schwarzenfels each of the eight pots which the oven contains has in its lower part a small orifice, which is stopped up during the melting, but is opened when it is nearly completed. It is by this that the workman allows the speiss which is collected in the bottom of every pot to flow out. Then he draws off the blue glass. This, running out quite red hot into the basin of cold water, explodes, breaks into pieces, and becomes easier to pulverize. When a pot is empty, it is not refilled immediately; the glass is first drawn from all the other pots; because, while charging with new material, the furnace would cool, and the temperature being too much depressed, it would not be possible to empty the last pot completely.

When they are all empty, a recharging takes place, and the melting is continued in the manner described. The cold glass is withdrawn from the water, put to drain in a wooden trough, and carried to the store.

During the melting there forms what is called *verre de sole*, or waste glass; it proceeds from a part of the contents running over the pots, or spilling by the breaking of the vessel. This glass collects on the sole of the furnace, runs out by the opening for the flame, and mixes with the ashes; it is gathered up, crushed, washed, and serves for an addition to the charges in greater or less quantity.

A Swedish smalt furnace, such as is in use in Modum, is represented by Figs. 4 and 5. It resembles substantially the German furnace, consisting of a circular furnace chamber in which the crucibles stand, which is encompassed by the circular wall, O, and surmounted by a dome, K, which is strengthened by an iron ring, L. There are six working openings, M, in the dome, corresponding to the six crucibles, and also six openings, called knee-holes, in the circular wall. These serve for emptying the pots: there are besides two larger ones, N, through which the crucibles are introduced, and which are walled up during the working. The pots, B, stand on a floor supported on the crown of the furnace A; they are heated from below, the flames striking through the opening, E, from the brick grate, C, the stoke holes of which, D D, as well as the ashpit, F, is approached by the steps, H H.

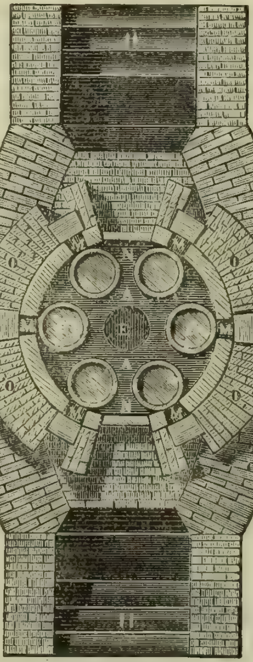
Fig. 4.



The operation does not differ materially from the German process. A pot holds about 3 cwt., and the yield of glass is about 80 to 90 per cent., the loss consisting chiefly of carbonic acid and moisture, and the remainder being speiss.

Grinding and Washing.—The blue glass after being quenched in water is next broken up in a stamping mill, the stampers of which are shod with granite, and also strike upon granite; or it is crushed between rollers, and reduced to powder by two granite mill stones, working under water in a wooden trough. After grinding some hours an orifice in the wooden case, which envelopes the mill stones, is opened; when the ground material, mixed with water, escapes through a series of large troughs arranged to receive it. In the first it stays only a few minutes, during which the coarsest smalt deposits. This is known as strewing sand, or strewing blue, since it is sometimes used for sprinkling the floors; but only a part of it reaches the market for the purpose, the rest being ground again with fresh glass.

Fig. 5.



In the next depositing trough the liquid stays somewhat longer, and in the third about a quarter of an hour or more. The deposits in these troughs form the usual marketable smalt.

The product obtained in the fourth and fifth settling vessels forms an inferior quality known as *eschel*, having a lighter colour. The production of this, and of the still more finely divided and lighter portions, is to be attributed in some measure to the fact that the glass is attacked by the water and partially dissolved, notwithstanding the high proportion of silica in its composition. Carbonate and arseniate of potash are also dissolved. The liquid run off from the fifth trough is run into the sumpf or pool, and then allowed to settle entirely. The product obtained, sumpf-eschel, is a very slightly coloured substance, and is usually dried and resmelted in the pots.

The colours obtained in this manner are then each submitted to a further washing with fresh quantities of water in troughs. During this operation the workman agitates the mixture with a wooden oar, and then leaves it to settle; and afterwards, by means of a hair-sieve with close meshes, he frees the liquid from any floating impurities. The liquid thus prepared is again run into another trough, and allowed to settle.

The sediment or deposited colours have next to be dried. For this purpose they are removed from the troughs and put upon tablets, either in close chambers heated with a stove, or else in drying rooms exposed to the air. When properly dried the resulting mass has still to be crushed, as it is very compact. For this purpose it is passed between rollers and racks moved by water, or sometimes two planks sliding upon one another, or else an ordinary mill is employed.

The powdered colour is then sifted, usually through riddles which are inclosed in cases.

At Querbach, when the azure is drained it is withdrawn from the troughs, to which it strongly adheres, and is carried to the breaking benches, where it is pulverized with mallets and carried to the roller. After this it is taken to the braying machine, which is formed of two wooden cylinders turning horizontally. The azure is placed in a hopper, from which it falls upon the cylinders, which reduce it to a very fine powder. It is then dried in a stove chamber, in the centre of which is a furnace, the flame and smoke from which, after passing through a flue which runs round the drying bed, enters the chimney. The bed is terminated by a brick ledge 4 inches in height. The stove chamber is furnished with a number of shelves, upon which the smalt is first spread to dry, being frequently turned over upon them with a rake. The drying is completed upon the bed of the furnace. The temperature of the room is kept at 105° to 112° Fahr. When sufficiently dry it is again submitted to the action of the braying machine.

The anhydrous azure is finally submitted to a last manipulation. It is carried into a chamber containing a number of close cases bearing the number or symbol of each shade. In the middle is another tightly closed case, inside which a hair sieve, placed under a hopper, is suspended on an axis. The smalt is poured into the hopper and falls into the sieve, which the workman shakes by giving the shaft an alternate backward and forward movement.

The sifted smalt is put into packages, then closed up in small fir casks containing half a hundredweight, but before being packed it is damped with a little water to prevent loss of the dusty substance.

The yield of marketable blue producible from the blue glass is about 3 tons of azure, or dark blue, for every 5 tons of glass.

The following analyses of smalt are by **Ludwig**. The Norwegian smalt was good and deep-coloured, and also the German high eschel, but the product given in the third column was an eschel only slightly tinted:—

	Norwegian Smalt.	German Smalt.	
		High Eschel.	Coarse Eschel.
Silica,	70·86	66·20	72·11
Oxide of cobalt,	6·49	6·75	1·95
Potash and soda,	21·41	16·31	20 04
Alumina,	·43	8 64	1·8
Ferric oxide,	·24	1·36	1·40

A good sample of smalt ought to contain not less than 12 per cent. of cobalt, and it should not effervesce on addition of hydrochloric acid, which would indicate adulteration with chalk. When washed with water it ought to settle completely in a short time; if the supernatant liquid is at all turbid, it should be examined for clay.

Henry Hussey Vivian took out a patent in 1851 for improvements in obtaining nickel and cobalt. He found that these, in quantities of considerable value, were contained in copper ores, either the produce of foreign countries or of England, and that, in the treatment of such for copper, these metals have been wasted, a portion of them remaining in the refined copper and deteriorating its quality, another being thrown away in the slags, and a third being contained in a product called white or hard metal, commonly used in the manufacture of nails or sold at an inferior price. The object the patentee had in view was the separation of the above-named valuable metals, and obtaining them in a marketable form.

The invention consists in the separation of nickel and cobalt, or either of them, in the form of arsenides, from ores, slags, or regulus, and other combinations or alloys of copper, which is effected by means of the affinity of nickel and cobalt for arsenic, and of copper for sulphur. Arsenical pyrites is added to the cobaltiferous copper matter (white metal) and roasted. By this means an arsenical bottom is obtained, in which is collected all the cobalt and nickel.

The amount of cobalt ores raised in Great Britain is very small, almost the only mine that either does or has produced it being East Pool, in Cornwall. In 1871, 3 tons were raised, valued at £120, while in 1872, 1 ton only was produced, being worth £20; and in 1873, 8 cwts., value £12, was all the yield. None was obtained in 1874.

History of Smalt Manufacture.—According to the account of Klotzsch and Lehmann, writing in 1650, the colour-mills were about a hundred years old, so that the invention would seem to fall about the year 1540. Christopher Schurer, a glass-maker at Platten, a place which belongs still to Bohemia, retired to Neudeck, where he established his business. Being once at Schneeberg, he collected some of the beautiful coloured pieces of "cobalt" which were found there, tried them in his furnace, and finding that they melted, he mixed some with glass metal, and obtained a fine blue glass. At first he prepared it only for the use of potters; but in course of time it was carried as an article of merchandize to Nuremberg, and thence to Holland; and as painting on glass was then much cultivated in Holland, the artists there knew better how to appreciate this invention. Some Dutchmen, therefore, repaired to Neudeck in order that they might learn the process used in preparing this new paint. By great promises they persuaded the inventor to remove to Magdeburg, where he also made glass from the cobalt of Schneeberg; but he again returned to his former residence, where he constructed a hand-mill to grind his glass, and afterwards erected one driven by water. At that period the colour was worth 7½ dollars (30*s.*) per cwt., and in Holland from 50 to 60 florins (about £4 to £5 of our money). Eight colour-mills of the same kind, for which roasted cobalt was procured in casks from Schneeberg, were soon constructed in Holland; and it appears that the Dutch must have been much better acquainted with the art of preparing, and particularly with that of grinding it, than the Saxons. In a little time more colour-mills were erected around Schneeberg, to the detriment of those at Platten. Paul Nordhoff, a Friedlander, a man of great ingenuity, who lived at the Zwitter-mill in Schneeberg, made a great many experiments in order to improve the colour, by which he was reduced to so much poverty that he was at length forced to abandon that place and to retire to Annaberg, where he established a colour manufactory by the aid of a merchant at Leipsic, of which he was made the director; and by these means rendered the Annaberg cobalt of utility.

This information is in some measure confirmed by Melzer, who says that the mines of Schneeberg, which were first discovered in the middle of the fifteenth century, had declined so much towards the middle of the sixteenth, that it was impossible to get any profit by them until the year 1550, when a greater advantage arose from the new method of using cobalt. About this period a contract was entered into with the Dutch, who agreed to take the roasted cobalt at a certain price. Lehmann says, but without giving his grounds, that a manufactory for making blue glass was erected by Sebastian Preusler between Platten and Eybenstock, so early as 1571, while Kosler, who died 1673, says that a century and a half before his time cobalt was sold as zaffre, but that the colour-mills in the country had been established only about sixty years (Beckman).

Uses.—Smalt has been employed in fresco painting and in the making of porcelain pottery, stained glass, encaustic tiles, &c. The paper manufacturer, who makes animal-sized papers for account-books, &c., also uses this substance to hide the otherwise yellow tint of his paper. Berzelius stated that the silicic acid contained in writing paper coloured with smalt blunted the points of steel pens. Paper tinted by smalt gives when calcined an ash having an azure blue colour, and often evolves when burnt the peculiar alliaceous odour due to the arsenious acid present in the smalt. There is usually some difficulty in keeping the smalt uniformly suspended in the pulp, so that one side of the paper thus coloured is generally darker than the other. Hence artificial ultramarine is often substituted in cheap papers, although it is not nearly so permanent.

A coloured glass like smalt is, of course, only attacked by agents which destroy glass, and as these are so few in number, and so rarely occurring, smalt exceeds most pigments in chemical indestructibility and consequent permanency. It is applicable to all purposes for which a cheap durable blue is required. It is used by house-painters, by bleachers for finishing off cambrics, lawns, and linens, by the washerwoman for domestic purposes, and by starch-makers.

Good smalt may be used for painting on and colouring glass, but is not so appropriate for fine and delicate work as fluxes prepared with pure oxide of cobalt; while for less delicate purposes the simple mixture for making smalt will do as well as the prepared pigment. Indeed, large quantities of roasted ore, mixed with the proper proportion of quartz powder, are sent into the market for this purpose under the name of zaffre. The proportion of the ingredients in the zaffre must be arranged so as to give the tint required, and this is ascertained by a process of testing similar to that already described in the case of smalt. The names of *smalt*, *eschel* (from *ashe*, from the alkaline ash employed), and *zaffre* (corruption of sapphire) were originally applied to the same product, viz., smalt, but they have since been used to designate different substances.

A blue pigment has also been prepared by precipitating solution of cobalt (obtained directly from the ore) with a solution of silicate of soda. The silicate of cobalt thus prepared has been recommended as the compound best suited for painting upon glass and porcelain, and for the manufacture of blue glass.

Smalt is distinguished in the market by certain marks, denoting the depth and quality of the colour and fineness of the powder.

Testing of Smalt.—Smalt is very permanent under the action of reagents, and the quantitative testing of it is performed similarly to that of glass. Hydrochloric acid ought to act upon it only slowly, but upon boiling the smalt should become yellowish, while with caustic potash solution it should remain unchanged. It should also resist ignition, and fuse at a high temperature to a blue glass.

The following complete analysis of a good azure smalt by Rivot will give some assistance in examining this colour:—

Silica,	56·4
Alumina,	3·5
Ferric oxide,	4·1
Cobalt oxide,	16·0
Nickel oxide,	None.
Lime,	1·6
Potash,	13·2
Lead oxide,	4·7

Thènard's Blue, or *Cobalt Ultramarine*, is a beautiful blue pigment, one of the best and most permanent known. It consists essentially of alumina coloured by oxide or phosphate of cobalt. Its formation is used as a blow-pipe test for the presence of alumina; the supposed alumina being moistened with solution of nitrate of cobalt and ignited, gives a blue colour in the case of alumina, while zinc would give a green and magnesia a pink red colour.

The preparation of Thènard's blue is usually conducted by the following process:—A solution of cobalt nitrate is precipitated by addition of solution of phosphate of sodium, and the precipitate well washed by repeatedly agitating with water, allowing it to subside, and pouring off the supernatant liquid. A solution of alum is then precipitated by addition of a solution of carbonate of soda, and this precipitate is also well washed with large quantities of water, by decantation as before.

The pasty precipitates are then well mixed, in proportion varying a little, but usually about 5 parts of the alumina precipitate to 1 part of the cobalt phosphate. The mass must be well incorporated by long stirring, and then dried and ignited in a well covered crucible, from which great care must be taken to exclude the reducing gases of the furnace, otherwise the colour is much injured. To do this the more effectually it is usual to put into the crucible, along with the charge, a small quantity of red oxide of mercury, which, being decomposed by the heat into oxygen and mercury, fills the crucible with an oxidizing atmosphere, while the mercury volatilizes, doing no harm.

Another modification of the process of making this colour is to mix solutions of the nitrate of cobalt and the alum together, and precipitate this solution with carbonate of soda, and the precipitate thus obtained is treated as before. This is not so good as the previous method, because there will be some amount of alkali that cannot be removed by washing, and the colour produced is not so good as when phosphoric (or arsenic) acid is present. (Louyet.)

The alum employed should be free from iron and zinc.

Another process consists in evaporating a mixed solution of cobalt sulphate and ammonia alum to dryness, and subjecting the residue to prolonged ignition to a high temperature in a wind furnace.

The colour of Thènard's blue very nearly approaches that of ultramarine, but it is more transparent, and by artificial light appears of a violet tinge, like most other of the cobalt colours. But Thènard's blue is a much more permanent colour than ultramarine, and indeed than other blue pigments. It is unacted upon by either hydrochloric acid or potash solution, and of course withstands the most intense ignition; nor is it at all poisonous, except when prepared from arseniate of cobalt, or when arsenic has been added to improve the tint. Thènard's blue is used by artists.

Cœruleum.—Under this name a blue pigment, consisting of tin oxide coloured with cobalt, has been prepared by Rowney & Co., and has the advantage over Thènard's blue of being less transparent, and in retaining its blue colour in gaslight. An analysis of the colour shows the following composition:—

Binoxide of tin,	49·66 per cent.
Oxide of cobalt,	18·66 "
Silica and sulphate of lime,	31·68 "

It is attacked by hydrochloric acid and by nitric, but is unacted on by caustic alkalies. It is used by artists both as an oil and a water colour.

Rinmann's Green. — According to WAGNER this pigment, which consists essentially of oxide of zinc coloured with oxide of cobalt, is prepared by precipitating a 10 per cent. solution of cobalt chloride with carbonate of soda, and mixing the washed precipitate with zinc-white to a reddish violet cream, which is then dried and ignited. There must be about nine times as much zinc as there is cobalt. Phosphate or arseniate of soda may be substituted for carbonate with beneficial result. Five parts of zinc-white to 1 of cobalt gives a deep dark green, but the above given proportions give a full grass-green colour. GENTELL recommends that alumina be mixed with the zinc oxide to the extent of 10 or 20 per cent.

The same qualities that recommend THÉNARD'S blue also apply to RINMANN'S green, viz., that it is unacted upon by caustic alkalies, hydrochloric acid, or by ignition. But it is attacked by ammonia. It is not poisonous when arsenic has not been used to prepare it, and in this respect is superior to most other green pigments.

Cobalt Bronze is a double salt of cobalt, phosphate of ammonia and cobalt, prepared at Pfannensteil, near Aue, in Saxony. It is a violet-coloured powder with a strongly metallic lustre, and resembles in general appearance the violet-coloured chloride of chromium.

Silicate of Cobalt, obtained by precipitating a solution of a cobalt salt with silicate of soda, is a blue powder that has been used for painting on porcelain.

Cobalt Yellow is the double nitrite of cobalt and potassium, for the preparation of which see "Separation of Cobalt." It has been used as a yellow colour in oil and water colour painting in consequence of its resisting the action of sulphuretted hydrogen and oxidizing agencies. It is also applicable, instead of cobalt oxide, as a blue pigment for the colouring of glass and for porcelain painting, and is to be recommended for this purpose because it is easily obtained in a pure state, and free from metallic oxides injurious to the colour.

COCHINEAL.—It is stated that as early as in the time of Moses the highly prized red colour used for dyeing the garment of the high priest was derived from an insect (*Jole*), which according to the accounts given appears to have been the same as that which later in Greece and Rome attained great importance, and continued to be the principal red colouring matter in the middle ages, especially amongst the Moors, long after the art of producing the Tyrian purple had died out. This insect is the *Coccigranum* of PLINIUS, or the *Coccus ilicis L.*, generally known by its Arabic name kermes, or alkermes. It lives upon the branches of the *Quercus coccifera L.*, a shrub of Southern Europe, Syria, and North Africa, and is only met with where this plant thrives.

Another species of *Coccina*, the *C. polonica*, which lives upon the roots of *scleranthus*, *herniaria*, and other plants in Northern Europe, was formerly collected and highly esteemed in Germany, Poland, and Russia, as a red dye; but on account of its sparse occurrence, was of much less importance than the former. Besides these there are other colour producing species, such as *C. uvae ursi* in Russia and *C. fabæ* in France, and last, but not least, the *C. lacca*, which furnishes the lac-dye and shellac.

Thus quite a number of species of this particular family of insects, the *Coccidæ* or *Gallinsecta* of the order of the *Hemiptera*, were known from the earliest ages, and made use of in the old world for the purpose of producing a red dye; but it was after the discovery of America that yet another, and by far the most important species, the cochineal, was introduced.

As a general characteristic of the whole tribe of the *Coccidæ* it may be mentioned that only the male insects are furnished with wings, whilst the females are wingless, very much larger, and generally of a largely extended spheroid shape; they are so stationary in their habit that, on first sight, their animal character may be often altogether overlooked. It is only the female insect which furnishes the dyeing material.

As a rule these insects affect only particular species of plants, and the females, generally in large numbers, fasten themselves on the more succulent parts, such as the leaves, young branches, and sometimes the roots.

Most of them produce and surround themselves with a peculiar secretion which exudes from their body, and which generally serves the purpose of a nest or shelter for the young brood. This secretion is in some cases of a viscid sugary nature; in others of a resinous character, as with the *C. lacca*, which in this way produces the shellac; but more commonly, as in the case of the cochineal and kermes, it appears in the form of a downy wool-like substance, composed of a special kind of wax similar to that which is produced by another species of this family, the *Coccus ceriferus*, and known in commerce under the name of "Chinese wax." (See CANDLE.)

The cochineal insect is a native of Mexico, where it had been employed by the Aztecs and Tezcucans for an indefinite period for the production of a red colour, and it was even to some extent cultivated by them for this purpose. On the invasion of that country in 1518 the Spaniards soon recognized its great tinctorial value, and subsequently the demand from Europe for this new article caused a great increase in its production, which was brought about by means of regular plantations which were laid out in the southern provinces of Mexico, especially in Tlascala, Oaxaca, Yucatan, Guatemala, and Honduras, and it soon became one of the most valuable articles of export from this newly acquired country. Mexico maintained for a long time the monopoly in the production of cochineal, and the Spanish governments exercised great vigilance in preventing its introduction into other countries. In the middle of last century they had recourse to the strange expedient of decreeing the destruction of all the plantations in Yucatan, in order to raise the price of the cochineal.

It was not until in the second quarter of this century that the cultivation of the cochineal insect was introduced into the south of Spain (Malaga and Valencia), Malta, Algiers, the Cape, Madeira, Java, and Teneriffe; but only in the latter island has it attained any importance, and indeed, at the present moment, more cochineal is exported from Teneriffe than from any other country.

LOPEZ DE GOMARA, in 1525, and PLUMIER, in 1692, gave the first description of the cochineal insect and the plant on which it lives; but nevertheless it was generally regarded as the seed of a plant, and this opinion continued prevalent, notwithstanding numerous publications on the subject by various authors, such as LISTER, who in 1672 justly regarded it as a kind of kermes, HARTSOECKER (1694), LEEWENHOECK, who made a microscopical examination of it in 1703, DE LA HIRE (1704), and GEOFROY (1714). At last all doubts were removed by RUUSCHER* who, in the year 1729, obtained direct information from cultivators of cochineal in Oaxaca. About 1757 a Mr. ELLIS obtained portions of the cactus plant, and observed that the specimens were full of the nests, in which the insect appeared in various states, from the most minute, when it traverses the plant, to the period when it fixes itself on the leaf. He also found by the assistance of the microscope the true male insect, in the parcels which had been sent to him from America; and in consequence of this discovery Dr. GARDEN caught in 1756 a male cochineal fly, which, he observes, is rarely to be met with. He supposes that there are from one hundred and fifty to two hundred females for each male.

The cochineal is only found upon certain species of cactus, such as *Cactus coccinellifer*, *C. opuntia*, *C. tuna*, and *C. Pereskia*.

Formerly a considerable proportion of the commercial cochineal was gathered from the wild growing plants; this was, however, of an inferior quality, and called *grana silvestra*. At the present time nearly all the cochineal which comes into the market is the produce of the regular cultivation of the insect, which is carried on in a systematic manner. This plantation cochineal is termed *grana fina*, *mestica*, or *mestique*.

The cochineal plantations are generally situated on slopes of valleys, or on hillsides which are sheltered against the cold winds. The season of rearing and gathering lasts about seven months, during which period the insects are collected three and sometimes four times.

The male insects resemble somewhat a middle-sized gnat, or still more the larger species of male aphides; they are of a red colour, and have two white wings. They fly about, and after having fructified the females, die. They live about four weeks, or half the time of the females. The females are very unlike the males, as they have no wings, and only move about when quite young, and still very small. They soon fix themselves with their proboscis upon the surface of the cactus leaves, and then assume a swollen spheroid shape, not unlike small dark red or purple berries, and begin to surround themselves with the peculiar white fluffy substance already referred to. In about two months they attain maturity, and then are gathered by being brushed from the plants with a feather, or a brush made of the stalk of a palm leaf, and killed at once, either by being immersed into boiling water or by being exposed to steam, or sometimes by being put on suitably heated plates. After having been carefully dried, they form the cochineal of commerce.

On the plantations special provision is made for securing a new crop by preserving at the end of the season branches of the cactus which are covered with female insects, and keeping them during the cold season under shelter. On the return of the warm season these females are put into small artificial nests, made of some downy or woolly looking material, and distributed over the plantation. As soon as the young insects are hatched they move about for a short time, and spread themselves over the cactus plants; however, they soon attach themselves on the surface of the leaves, as already mentioned, and in turn attain their maturity in about two months.

According to the condition in which the insects are gathered they lose from two-thirds to three-fourths of their weight on drying, and it requires from 40,000 to 60,000 insects to produce 1 lb. of dry cochineal. A plantation of about 2½ acres requires the attendance of three men, and yields from 500 to 600 lbs. of cochineal.

In the state in which the cochineal is found in commerce it bears hardly any resemblance to an insect, and judging from its appearance only, it is by no means surprising that the belief in its vegetable origin should have endured for so long a time.

The cochineal occurs in several distinct forms, which are now generally classed under three different denominations, namely, the grey or silver cochineal (*Jaspeada*), the black (*Negra*), and the shelly cochineal.

It is generally stated that this different appearance is simply due to the mode of killing and preparing the insects, and accordingly the silver cochineal is said to be obtained by drying the insects on hot plates or in ovens, whilst the black cochineal is produced by momentary immersion in boiling water and subsequent drying. The third variety, or shelly cochineal, generally of a dark reddish or brown colour, differs in other respects from the former kinds, as will be pointed out hereafter. This variety has been introduced in steadily increasing quantities during the last twenty years, but nothing reliable is known about its mode of production.

The cochineal appears in the form of somewhat irregular shrivelled up grains, wrinkled with deep contorted furrows, which in the case of the silver cochineal are more or less filled up with a white powdery substance, the remains of the peculiar downy secretion with which the insect surrounds itself; in the black cochineal this latter substance or white coating has been partly or nearly entirely removed by the process of immersing the insects into boiling water, and therefore the dried insect appears in its proper colour.

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* Phil. Trans. vol. xxxv. p. 265.

The shelly cochineal, on the other hand, differs from the former very considerably. As its name indicates, the individual insects have the appearance of nearly empty shells, which show but few and much less pronounced wrinkles on the upper convex side, whilst the lower part is drawn in so as to form a concave depression.

In bringing cochineal in contact with warm water the grains generally float at first, but they soon swell up, and becoming quite soft and assuming gradually the spheroid berry-like shape of the live insect, sink under the surface. In this condition some of the characteristic insect features may be readily distinguished by the aid of a magnifying glass; remnants of the legs, the proboscis, and head, are often discernible, although these fragile parts of the insect have mostly been removed by the process of sifting and garbling to which the dry insects are submitted previous to their being sent into the market. To the unassisted eye, however, these swollen and softened grains present much greater resemblance to some kinds of berries, and this becomes still more striking when, on squashing or cutting them open, it is found that the thin skin incloses a soft dark-red pulp, in which generally a multitude of small grains are suspended, which might very easily be mistaken for seeds. In reality these grains are the eggs or young brood of the insect, and they form a very large portion of the bulk of the silver and ordinary black cochineal, whilst in the fine shelly cochineal they are either present in very much smaller numbers, or are wanting altogether. This seems to constitute the characteristic of the shelly cochineal, and it would follow from this that the shelly cochineal represents the insect in a different state of development. The better kinds of this variety do not show any sign of the white secretion, and consist of very large and regularly shaped insects, of a dark reddish-brown colour and smooth shiny surface. Other kinds consist of small, irregular, very thin, and light shells, of much inferior appearance, which, however, not unfrequently are found to be superior in yield of colouring matter to any other kind.

As the eggs do not contribute to the yield of colouring matter, it may be inferred that the heavy and solid-looking sorts of silver cochineal are by no means the most valuable; and this having been now pretty generally recognized, the preference is given to the shelly sorts. In Teneriffe, where of late years the cultivation of cochineal has made the greatest progress, about three-fourths of the cochineal produced is what is termed black shelly, and only one-fourth silver cochineal. In Honduras, on the other hand, four-fifths of the produce is silver cochineal.

Formerly the silver cochineal was considered to be superior, and not unfrequently the appearance of silver cochineal was imparted to other sorts by the application of some white powder, such as talc, carbonate of lead, &c. This and other sophistications of cochineal are now of very rare occurrence. Occasionally a parcel is met with from which part of the colouring matter has been extracted.

At the end of the season, when all the insects are removed from the plants, some are still small and imperfectly formed; these are, after drying, separated by sifting and sold as an inferior article under the name of "granilla."

It is generally supposed that the introduction of the aniline colours has very materially diminished the consumption of cochineal; but although this is no doubt true with regard to some special applications, the following table of importation to London during the last fourteen years shows, on the contrary, a slight increase.* From this table it will also be seen that Teneriffe produces now the largest quantity, whilst Honduras has fallen away considerably. London is by far the most important market for cochineal; Bordeaux, Havre, Marseilles, Amsterdam, and Rotterdam (the two latter places from Java), import now only small quantities:—

COCHINEAL IMPORTED INTO LONDON.

Date.	Honduras.	Mexican.	Teneriffe.
	Lbs.	Lbs.	Lbs.
1861	1,750,720	426,400	1,403,200
1862	1,188,000	129,600	1,155,680
1863	1,807,520	122,880	1,093,600
1864	1,274,080	372,480	899,520
1865	1,082,080	150,400	1,385,440
1866	966,240	197,760	2,019,680
1867	1,269,600	185,120	3,085,280
1868	529,920	271,520	3,106,080
1869	614,080	188,320	3,708,160
1870	614,880	300,480	3,903,520
1871	384,000	271,200	4,308,640
1872	362,240	199,360	3,082,080
1873	375,680	359,040	3,046,400
1874	417,440	394,720	3,041,120
Totals,.....	12,636,480	3,569,280	35,238,400

As one of the most important dyeing materials, cochineal became the subject of chemical examination at a very early period, and in the course of time a considerable number of investigations were published by various chemists.

It was of course the colouring matter contained in the cochineal which chiefly attracted the attention of chemists; but although a good deal has been done towards making out the chemical history of this substance, much still remains to be cleared up in this respect.

As might be expected, the results of those researches which were carried out in the earlier part of this century are now of but little value; organic chemistry being then still in its infancy, the methods available for research were inadequate to deal with so complicated a subject. It may therefore suffice to give here merely a brief outline of the results obtained by the earlier investigators. Johann F. John published, 1813 ("Chemische Schriften"), the following analysis of cochineal, without however describing the method employed in separating the various constituents:—

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* The use of kermes, on the other hand, has been discontinued now in Europe, and it seems to be no longer an article of commerce.

Colouring principle (semi-solid, soluble in water and alcohol),	50·00
Gelatine,	10·50
Waxy fat,	10·00
Modified mucus,	14·00
Membrane,	14·00
Alkaline phosphates and chlorides, phosphates of lime, iron, and ammonia,	1·50
	100·00

Pelletier and Caventou* communicated in 1818 a long memoir to the Institute de France, in which they described their results obtained in the chemical examination of cochineal. They first removed the fatty bodies by extracting the cochineal with boiling ether, in which the colouring matter was found to be but slightly soluble, and obtained by these means stearin, olein, and an aromatic acid, which, however, was not further examined. The exhausted residue was then treated with alcohol of 40° B., which dissolved the colouring matter, together with a small quantity of fatty and nitrogenous substances. On cooling this solution they obtained by spontaneous evaporation a granular red residue of a semi-crystalline appearance, and which they considered to be the colouring matter still contaminated with nitrogenous matter (*matière animalisée*) and some fatty substances, the greater part of which remained undissolved when treated with strong cold alcohol. By repeating this operation once or twice they considered that the substance was obtained almost in a state of purity. In order to remove the last traces of foreign matter it was dissolved in strong alcohol, and an equal volume of ether added, which precipitated the colouring matter and retained the fatty matter which was still adhering to it. The colouring matter thus obtained was named carmine (*carminium*). It is of a deep purple-red colour, very soluble in water, forming an intense purple liquid; in alcohol it is less readily soluble, and quite insoluble in ether and the fixed and volatile oils. The aqueous solution, when free from animal matter, is not precipitated by dilute acids, but its colour is changed to a yellowish red tint, which reverts to purple on neutralizing with an alkali.

Of the alkaline earths, lime only produces a precipitate; hydrate of alumina absorbs the whole of the colouring matter from an aqueous or alcoholic solution, but the presence of alum prevents this reaction. Neutral salts of lead merely change the colour of the solution to a violet; but the neutral acetate precipitates the colouring matter, forming a dark purple compound, from which the former can be recovered by decomposing the compound with sulphuretted hydrogen. These are the principal properties of the pure colouring matter of cochineal as obtained by Pelletier and Caventou. In a later communication (1832) Pelletier† gave the composition of the colouring matter as prepared by himself and Caventou, as follows:—

Carbon,	49·33	Oxygen,	40·45
Hydrogen,	6·66	Nitrogen,	3·56

T. Preisser, in an elaborate paper ("Rev. Scient." 16, 53) on the origin and nature of colouring matters, affirmed that he obtained by the action of sulphuretted hydrogen on the lead compound of the colouring matter of cochineal, a perfectly colourless well crystallized substance, which according to his statements was soluble in water and alcohol, but less so in ether, and assumed in contact with the atmosphere the purple red of the colouring matter of the cochineal. He also asserted that the aqueous solution of this substance gave, with acetate of lead, a white precipitate, which on exposure to the air assumed a purple tint. A. E. Arppe ("Liebig's Ann." vol. iv. p. 101) on repeating the experiments of Preisser, obtained a red solution, which on evaporation was converted into white crystals of oxalic acid, the formation of which was due to the action of nitric acid contained in the so called oxide of lead employed, which in fact was a basic nitrate. This explains to a certain extent the results of Preisser's experiments; but as regards his remarkable "chromogen," it may be assumed that in describing it he has rather drawn on his imagination. Arppe made some further attempts to separate the colouring matter in a pure state, but it would appear from the description of his mode of proceeding that he was unsuccessful.

Subsequently this subject was taken up by Warren de la Rue,‡ and submitted to a careful examination, which led to the separation of the colouring matter in a pure state, and the discovery of the nitro-coccusic acid.

After repeating the experiments of the former investigators on a considerable scale, in order to obtain the colouring matter in quantity, W. de la Rue devised the following method for separating this substance in a pure state. The aqueous decoction of cochineal is precipitated with acetate of lead, the bulky dark purple-coloured compound is washed by decantation with boiling distilled water, and then decomposed by sulphuretted hydrogen. The deep red liquid so obtained is freed from sulphuretted hydrogen by boiling, and then precipitated a second time with acetate of lead previously mixed with some acetic acid; the precipitate, after having been thoroughly washed as before, is decomposed with sulphuretted hydrogen. The liquid after filtration is evaporated on a water bath to dryness, and the dark residue dissolved in absolute alcohol. In order now to remove the small quantity of phosphoric acid which is still contained in this product, the alcoholic solution is digested with about the fourth part of the lead precipitate, which has been reserved for this purpose from the second precipitation, and after drying has been reduced to a fine powder. The alcoholic solution is then filtered, and after a part of the alcohol having been distilled off, is mixed with an equal volume of ether, which throws down a red flocculent matter containing some nitrogenous impurities still retained in the liquid. After filtration and distilling off the alcohol and ether, the substance remains behind in a pure state,

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* Annales de Chimie et Physique, ser. 2, tome viii. p. 250. Journ. de Pharm., ser. 2, tome iv. p. 193.

† Ann. de Chim. e.d. Physique, ser. ii. tom. ii. p. 194.

‡ Mem. and Proceed. of the Chem. Soc. Part xxii. 1847.

When thus prepared the colouring matter of cochineal forms a purple brown friable mass, transparent when viewed under the microscope, easily pulverized to a fine red powder, soluble to any extent in water and alcohol, but only slightly so in ether, which, however, does not throw it down from its alcoholic solution when it is free from nitrogenous matter.

This substance, possessing well marked properties, was named by W. de la Rue *carminic acid.*

Pure carminic acid is soluble without (?) decomposition in concentrated hydrochloric and sulphuric acids. Its aqueous solution is decomposed by chlorine, iodine, and bromine, which change its colour to yellow, and the latter, on warming or by standing, gives a yellow precipitate soluble in alcohol. Nitric acid even in a highly diluted state decomposes it, giving rise to the formation of oxalic and nitrococcusic acid. It bears a temperature of 136° C. without decomposition; on gradually increasing the temperature a quantity of an acid liquor is produced, and at red heat it intumesces and gives off a small quantity of red fumes, which condense; it gives no trace of oily matter.

The fixed alkalies and ammonia change the scarlet red colour of its aqueous solution to a deep purple; on mixing alcoholic solutions, however, purple precipitates are produced, which are the compounds of carminic acid with the alkaline base.

The alkaline earths produce with the aqueous solution likewise purple precipitates; sulphate of alumina gives no precipitate, but on addition of a drop of ammonia the carminic acid is precipitated in combination with alumina, forming a beautiful crimson lake; acetates of lead, copper, zinc, and silver, give purple precipitates. The latter is, however, immediately decomposed, and metallic silver is deposited; the nitrates of lead, mercury, and silver give reddish precipitates; protochloride and bichloride of tin do not form any precipitate, but change the colour to a deep crimson.

It is a matter of great difficulty to obtain even the insoluble metallic compounds of carminic acid in a pure state and of constant composition, for it appears that they carry down some of the precipitants. Only the copper salt could be obtained in a sufficiently pure state to serve for analysis and the determination of the atomic weight of carminic acid.

As the mean of several analyses W. de la Rue obtained the following percentages:—

		Theory.	Experiment.
C_{14}	168	54·19	54·13
H_{14}	14	4·52	4·62
O_8	128	41·29	41·25
	310	100·00	100·00

which led him to the adoption of the formula $C_{14}H_{14}O_8$, with which the results obtained by the analysis of carminate of copper also agreed:—

		Theory.	Experiment.
C_{14}	168	48·05	47·62
H_{14}	14	4·01	4·12
O_8	128	36·61	36·74
CuO	39·6	11·33	11·52
	349·6		100·00

Schützenberger (1858, "Ann. Chim. Phys." (3), vol. liv. p. 52), who subsequently investigated carminic acid, noticed a considerable difference in the composition of carminic acid of different preparations, and arrived at the conclusion that the carminic acid, as obtained by W. de la Rue, although otherwise pure, was a mixture of several substances. He found that by adding to a concentrated solution of carminic acid in absolute alcohol five or six times its volume of ether a red substance was precipitated, and on evaporating then the pale coloured alcohol-etheric solution a crystalline mass, composed of red needles and dark red granular crystals, was obtained. With boiling ether, which dissolves the latter, these two substances could be separated, and on being finally submitted to analysis the needle-shaped crystals gave numbers which agreed with $C_9H_8O_6$ (oxycarminic acid), whilst the granular crystals appeared to be $C_9H_8O_5$ (carminic acid.) Schützenberger considers it probable that several other coloured substances are contained in the carminic acid as originally prepared by W. de la Rue.

Later C. Schaller ("Bull. Soc. Chim." (2) vol. ii. p. 414: 1864), prepared carminic acid by precipitating the aqueous extract of cochineal with neutral acetate of lead, acidulated with acetic acid, and decomposing the thoroughly washed precipitate with sulphuric acid; the filtrate was then precipitated a second time, and the precipitate again decomposed with sulphuric acid, but carefully avoiding an excess of sulphuric acid in order to retain the phosphoric acid in the precipitate; the filtrate was now precipitated a third time, and the well-washed precipitate decomposed with sulphuretted hydrogen. After filtration the red liquid was evaporated to dryness, and the residue dissolved in absolute alcohol, when on spontaneous evaporation the carminic acid separated in crystalline nodules, mixed with yellow six-sided tabular crystals of another substance. Cold water dissolved the carminic acid, and left the latter undissolved; by evaporating the aqueous solutions and crystallizing the residue once more from absolute alcohol, the carminic acid was obtained in a pure state. The carminic acid prepared according to this method, on being analyzed, gave numbers which lead to the formula $C_9H_{10}O_6$, which differs from Schützenberger's formula only by H_2O. Schaller considers the carminic acid as a bibasic acid forming acid $\left.\begin{matrix}C_9H_8O_5\\MH\end{matrix}\right\}O$, and neutral, $\left.\begin{matrix}C_9H_8O_5\\M_2\end{matrix}\right\}O$, salts. The neutral sodium salt is obtained as a precipitate by mixing solutions of carminic acid and caustic soda in absolute alcohol. From an aqueous solution this salt crystallizes in nodular masses. On submitting a solution of carminic acid to the action of nascent hydrogen a colourless liquid is obtained, which resumes its red colour on exposure.

Although the results obtained by De la Rue, Schützenberger, and Schaller, agree well with regard to the general properties of carminic acid, it will be seen that they differ very materially with regard to the composition. The different formulæ derived from the results of analyses require:—

SCHALLER.	DE LA RUE.	SCHUTZENBERGER.
$C_9H_{10}O_6$	$C_{14}H_{14}O_8$	$C_9H_8O_5$
C 50·5 p. cent.	54·1 p. cent.	55·1 p. cent.
H 4·7 p. cent.	4·6 p. cent.	4·1 p. cent.

These discrepancies are too considerable to be ascribed to mere accident, and, indeed, can only be accounted for by assuming that the colouring matter of cochineal is a mixture of several very similar substances. Further examination being therefore required to clear up this subject—

HLASIWETZ and GRABOWSKI ("Liebig's Ann." 141, p. 329: 1867), took up this investigation, and succeeded in establishing the important fact that carminic acid is a glucoside, for on treating it with boiling dilute acids it was found that it splits up into a peculiar kind of sugar and a new substance, which they named *carmin-red.* By effecting this decomposition it was clearly proved that none of the formulæ hitherto proposed expressed the true composition of carminic acid.

HLASIWETZ and GRABOWSKI proceeded in the following way:—The precipitate of carminate of lead produced by acetate of lead in a filtered decoction of cochineal, after having been well washed, was decomposed with dilute sulphuric acid. To the dark red filtrate, after having been freed from lead by sulphuretted hydrogen, was added a small quantity (10 c.c. acid to the liquid obtained from 1 lb. of cochineal) of sulphuric acid, and then boiled for several hours. From the apparently unchanged liquid the sulphuric acid was now removed. By the careful addition of carbonate of barium, and after filtration, the liquid was precipitated with acetate of lead. This lead precipitate contained the carmin-red, whilst in the liquid the sugar remained dissolved. The liquid having been freed from lead by sulphuretted hydrogen was evaporated at a low temperature until a syrupy residue was left; this was found to be a mixture of the new sugar with a barium compound of the same, which could be separated by means of alcohol.

The analyses of these substances gave numbers agreeing with the formulæ, $C_6H_{10}O_5$ (dried at 50°), $C_6H_8O_4$ (dried at 100°), and $C_6H_9BaO_5$ (dried at 100°).

In order to separate the carmin-red from its lead compound it was found advantageous to effect the decomposition with dilute hydrochloric acid. The resulting red solution having been filtered off from the chloride of lead is freed from some dissolved lead by sulphuretted hydrogen, and then evaporated at a gentle heat.

Carmin-red so prepared forms a dark purple mass, which shows a green colour in reflected light; its powder is dark vermilion red, readily soluble in water and alcohol with red colour, but insoluble in ether. On being burnt it leaves a trace of ash, which contains lime, phosphoric acid, and a trace of iron. Its analysis led to the formula $C_{11}H_{12}O_7$.

The properties of this substance very much resemble those of carminic acid; it forms dark purple saline compounds with the alkalies, which are insoluble in alcohol, but soluble in water, with a violet colour, and these solutions give, with the chlorides of calcium, barium, strontium, zinc, &c., dark violet precipitates.

Several of these compounds (dried at 130°) were analyzed, and gave numbers agreeing with the following formulæ:—

$$C_{11}H_{10}K_2O_7,\quad C_{11}H_{10}BaO_7,^{*}\quad C_{11}H_{10}CaO_7,^{\dagger}$$

According to these results carminic acid must be considered a glucoside, and on assuming that its decomposition by acids takes place, as is invariably the case with this class of substances, under assimilation of water, this reaction may be represented by the following equation:—

$$\underset{\text{Carminic acid.}}{C_{17}H_{18}O_{10}} + 2H_2O = \underset{\text{Carmin-red.}}{C_{11}H_{12}O_7} + \underset{\text{Sugar}}{C_6H_{10}O_5}.$$

The formula $C_{17}H_{18}O_{10}$ for carminic acid requires C 56·1 and H 4·4, which are nearest approached by the results of SCHÜTZENBERGER'S analysis.

Further investigation is, however, required to find a proper interpretation for the crystallized carminic acids observed by SCHÜTZENBERGER and SCHALLER.

Nitro-coccusic acid.—As already mentioned, carminic acid is readily acted on even by dilute nitric acid under violent evolution of nitrous fumes. The red colour of the carminic acid is instantly destroyed, and changed into orange. On bringing the action of the nitric acid to a termination by the application of heat, and keeping the mixture for some time at the boiling point, the resulting yellow liquid, after sufficient concentration, solidifies on cooling to a crystalline mass which, besides a large quantity of oxalic acid, contains the nitro-coccusic acid. In order to separate the latter, this crystalline mass is dissolved in a large quantity of boiling water, and a solution of nitrate of lead is added as long as a precipitate of oxalate of lead is formed. After filtering, the yellow liquid is evaporated, when some more oxalate of lead separates, which is removed, and after further concentration the nitro-coccusic acid crystallizes on cooling. By repeated recrystallization from water it is obtained in a pure state. LIEBERMANN and VAN DORP have found it advantageous to use carmine instead of carminic acid, as DE LA RUE has done, for the preparation of this acid; and for the purpose of separating the oxalic acid they found it more convenient to dissolve the mixed acids in hot water, and then add some nitric acid, which causes the nitro-coccusic acid to separate on cooling, as it is but very little soluble in water containing nitric acid.

The nitro-coccusic acid is of a pale straw colour, or, if quite pure, colourless, crystallizing in rhombic plates, but exhibiting very different aspects according to the circumstances under which it is crystallized. It resembles somewhat picric acid (Trinitrophenol), and like this substance stains skin, wool, &c., yellow. It is soluble in cold, but more so in hot water, soluble in alcohol, and very soluble in ether; all these solutions being of a deep yellow On being heated the acid deflagrates violently

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* Ba = 137.

† Ca = 40.

Nitro-coccusic acid forms well crystallized salts of a deep yellow or orange colour; they are all readily soluble in water, and most of them in alcohol; and when heated to near 200° decompose with more or less violence. De la Rue by numerous analyses of the acid, and several of its salts, conclusively proved its formula to be $C_8H_5(NO_2)_3O_3$, and its salts $C_8H_3(NO_2)_3M_2O_3$. On boiling the aqueous solution of the acid with an excess of oxide of silver carbonic acid is evolved and a new acid is formed, which, however, has not been fully analyzed (probably Trinitrocresol). It will be noticed that the composition of nitro-coccusic acid bears no direct relationship to that of carminic acid, and taking into consideration that, according to Liebermann and Van Dorp, only about 8 per cent. is obtained, whilst a very large quantity of oxalic acid is produced simultaneously, it becomes evident that nitro-coccusic acid is not a direct derivation, but the product of a more complex reaction.

Nitro-coccusic acid has the same formula as trinitroanisic acid, but De la Rue has already shown that it is not identical with this acid.

Liebermann and Van Dorp, who have recently re-examined this acid, succeeded in clearing up its chemical relation by effecting its decomposition by heating it with water in sealed tubes to a temperature of 180°. Under these circumstances it splits up into carbonic acid and trinitrocresol, the latter being identical with that which Duclos obtained from coal-tar cresol.

Accordingly, nitro-coccusic acid is in reality one of the several isomeric forms of trinitro-cresotinic acid, and the above reaction corresponds with the decomposition of cresotinic acid into carbonic acid and cresol when heated, as observed by Kolbe and Lautemann—

$$C_8H_8O_3 = CO_2 + C_7H_8O.$$
$$C_8H_5(NO_2)_3O_3 = CO_2 + C_7H_5(NO_2)_3O.$$

Coccinine ($C_{14}H_{12}O_5$.). — Hlasiwetz and Grabowski obtained this remarkable derivative by submitting carmin-red or carminic acid to the action of fused potash. It is prepared by adding 1 part of these substances to 3 parts of caustic potash (when carminic acid is employed, 4 to 5 parts) dissolved in a little water, and heating the mixture carefully in a silver basin until the black colour has changed into a brown, and dissolves with a golden brown colour in water. The fused mass is then dissolved in water super-saturated with sulphuric acid, and after filtration the acid liquid is repeatedly shaken up with ether. The etheric solution leaves on distillation a crystalline residue, which after recrystallization from alcohol furnishes the coccinine in a pure state. When carminic acid, instead of carmin-red, has been employed, oxalic and succinic acids are obtained along with the coccinine, and are removed by washing with water. The yield of coccinine at the best is but small, and depends very much on the care with which the operation is carried out.

Coccinine crystallizes in yellow rectangular plates, which are insoluble in water, readily soluble in alcohol, but less so in ether. In dilute alkalies it dissolves with great facility, forming yellow solutions which, on contact with the air, turn at first green, and then this colour gradually passes through violet into a beautiful purple red. The alcohol solution when brought in contact with sodium amalgam turns likewise green, but on subsequent exposure to the air assumes a deep indigo colour, and deposits an amorphous substance of the same colour. Coccinine appears to form definite compounds with bases of a pale yellow colour, but they are so changeable that they could not be obtained in a pure state.

Ruficoccine ($C_{16}H_{10}O_6$.).—According to Liebermann and Van Dorp carmin-red and carmine dissolve in concentrated sulphuric acid without change, but on heating the solution to 125° the colour changes into a violet; and if after the temperature having been kept for several hours at 130° to 140° the liquid is poured into water a dark precipitate is produced, which is composed of ruficoccine and another new substance. After thorough washing with water and drying it is exhausted with boiling alcohol, which on evaporation leaves the ruficoccine. After repeated washing with water and recrystallization from alcohol this substance is obtained in the form of a brick-red powder. It is but very little soluble in water; but on heating it in a sealed tube with water to 200°, on cooling a voluminous mass of orange-coloured needles is obtained.

Ruficoccine is but sparingly soluble in ether, but dissolves more freely in alcohol. These solutions show a fine greenish yellow fluorescence. It is readily soluble in alkalies, forming at first brown or brown-red solutions, which, on the addition of an excess of alkali, assume the colour of the rosaniline salts. The calcium compound is a dark violet precipitate; when dry a black powder, having the composition $C_{16}H_8CaO_6$. In concentrated sulphuric acid ruficoccine dissolves with a violet red colour. When heated it gives off red fumes and yields a small quantity of a red sublimate. By heating ruficoccine with zinc dust a solid hydrocarbon is produced, which sublimes in white plates, melting between 183° and 188°. By oxidation this hydrocarbon, which appears to be $C_{16}H_{12}$, yields a quinone resembling anthraquinone, but melting at 250°.

The quantity of ruficoccine produced by the action of sulphuric acid on carmine amounts to about 10 per cent., whilst of the insoluble bye-products mentioned above as much as 30 per cent. are obtained. This latter substance is a black powder which dissolves in the alkalies, and appears to have the formula $C_{32}H_{20}O_{13}$. When heated it chars and does not yield any hydrocarbon on being heated with zinc dust. With nitric acid it furnishes, however, nitrococcic acid and oxalic acid. On being heated with a solution of baryta for five or six hours a solution is obtained which gives, with hydrochloric acid, a brown precipitate soluble in alcohol, ether, and benzol, and with violet colour in the alkalies. This substance heated by itself gives off red fumes, and with zinc dust furnishes a hydrocarbon which appears to be identical with the one obtained from ruficoccine.

Ruficarmine, $C_{16}H_{12}O_6$.—On heating an aqueous solution of carmin-red in a sealed tube to 200°, its dark red colour changes into yellow, whilst a dark resinous body is deposited. This substance differs from carmin-red by its insolubility in water, and from ruficoccine by its great solubility in alcohol and ether; in the alkalies it dissolves, like these substances, with violet colour. As obtained by the precipitation of the alcoholic solution, by careful addition of water and a little hydrochloric acid, it forms a beautiful red powder.

On evaporating the aqueous extract of cochineal, from which the colouring matter has been removed by precipitation with acetate of lead, there remains a dark-coloured, syrupy liquid of a very complex character. If the concentrated liquid is allowed to stand for a while a white chalky matter subsides, which was originally recognized by W. DE LA RUE, and identified with *tyrosine.*

Besides this, several other crystalline substances, generally met with in animal extracts, have been noticed, as for instance *guanine* and *inosite*, which both appear to be present in not inconsiderable quantities; and on working with larger quantities of cochineal, for the purpose of preparing carmine or other colours, these otherwise rare substances may be obtained with advantage from this source. (HUGO MÜLLER).

Cochineal Wax, or Coccocerine.—The peculiar downy, wool-like secretion with which the female cochineal insect surrounds itself, and which is found to some extent still adhering to the silver cochineal and causing its white chalky appearance, is a kind of wax, which, however, differs from all known substances of this kind by its sparse solubility in the ordinary solvents and its high melting point. This cochineal wax, or *coccocerine*, is best obtained by treating silver cochineal, or, still better, the siftings of this article, with boiling benzol or its higher homologues, in which it is readily soluble. On cooling it separates almost entirely from this solution, and by repeated crystallization from the solvent it may be obtained in minute colourless crystals melting at 105° C. In alcohol and ether this substance is but very little soluble, and it is probably on this account that it was considered formerly to be of a mineral origin. In chloroform and disulphide of carbon, especially when hot, it is readily soluble. A solution of alcoholic potash saponifies the coccocerine and separates coccocerylic alcohol, whilst coccocerate of potash remains in solution. Concentrated sulphuric acid effects a similar decomposition. (HUGO MÜLLER.)

Spectroscopic Character of the Colouring Matter of Cochineal.—It is a matter of considerable interest that an aqueous extract of cochineal, although not showing by itself any characteristic features when examined by the spectroscope, on addition of ammonia, which turns the scarlet tint of the solution into a violet, exhibits two dark absorption bands between the FRAUENHOFER lines D and E, like those of blood, one situated at 8° the other at 9°—10° of a spectroscope having a scale of 20°, in which the sodium line falls at 7·7. (CAMPANI, *Gazzetta Chimica Italiana*, i. 471).

Valuation of Cochineal.—It is obviously impossible to judge positively of the quality of cochineal by its physical characters only, or in other words to estimate the amount of colouring matter contained in it by mere ocular inspection, yet this is still the common practice in commerce.

Various methods have been proposed for estimating the value by chemical means, which however, although simple enough, do not seem to furnish reliable results. The quantitative determination of the colouring matter by direct methods not being attainable, recourse must be had to comparative experiments. Accordingly the results of all these processes are obtained by comparing with standard specimens of cochineal the amount of particular reagents required, either to destroy or to remove the colour from the decoction of the weighed sample to be examined. For this purpose ROBIQUET proposed a solution of bleaching powder; PENNY a mixed solution of ferricyanide of potassium with caustic potash. In both these methods the colour is destroyed; on the other hand, ANTHON precipitates the colouring matter with alumina, and in a similar manner BLOCH makes use of a standard solution of acetate of lead.

From what has been said about the complex composition of cochineal, and also of the colouring matter itself, which appears to be a mixture of several substances, it is obviously very unlikely that these chemical methods can give any reliable results; for, quite apart from the fact that there are along with the colouring matter substances contained in the cochineal, which are in a like manner affected by the reagents employed, it is more than probable that also the tinctorial qualities of the several colouring matters contained in cochineal vary considerably. Consequently a method, to be of any practical value, would be required to take also cognizance of the relative quantities of the substances which constitute the colouring matter; with our present knowledge of the subject this is, however, unattainable.

The methods made use of in dyeworks for ascertaining the quality of cochineal consist in making dyeing experiments on a small scale, and by comparing the effect of the decoction of a given sample with that of a standard specimen of cochineal, on pieces of mordanized cotton, woollen, or silk stuff. In this way not only the strength, but also, and what is often more important, the quality or tint of the colour contained in the sample can be ascertained.

Distinction of the Cochineal Red from other similar Red Colours.—An aqueous decoction of cochineal, although bearing a great similarity in its behaviour towards various re-agents with a solution of carminic acid, shows some deviations, which generally are ascribed to the presence of some nitrogenous substance still unknown.

LASSAIGNE asserts that the colouring matter contained in the kermes is identical with that of cochineal;

experimental proofs of this are however still wanting. On the other hand, it is stated that the tints produced with kermes are much less brilliant, although more stable and less readily acted upon by chemical re-agents; also that cotton cannot be dyed with kermes.

The colouring matters of Lac dye and the other *Coccidæ* bear also a strong chemical resemblance to that of cochineal, but they also have as yet not been sufficiently examined to ascertain their true chemical nature.

The colouring matter of the red dye-woods, such as Brazil-wood, Sapan-wood, Peach-wood, &c., resembles in many respects that of cochineal, but the colours obtained from them are not nearly so rich, nor are they as stable. Chemically they may be readily distinguished by their calcium compound, which is of a violet colour and readily soluble in water, whilst that of cochineal-red is of a dark purple, almost black colour, and insoluble in water.

The application of cochineal in the arts is now almost entirely confined to the production of carmine and the brilliant scarlet dye on silk, and especially on wool. These colours have as yet not found a substitute amongst the numerous red-colouring matters derived from coal tar; none of these approach the peculiar and brilliant tint of carmine, or the scarlet on silk or wool obtainable from cochineal.

Carmine.—It is uncertain when this beautiful pigment was originally discovered, but as early as 1656 Homberg published a recipe for preparing it, and at that time it was already a well-known colour. According to Wiegleb,* it was accidentally discovered in Florence (or Pisa) by a Franciscan monk. In those days, and even up to recent times, cochineal was considered to possess some valuable medicinal properties, and it was during the process of preparing some medicament from it that the formation of carmine was first observed. Possibly its name is due to its original connection with some such medicinal preparation, and may have been derived from the Latin word *carmen* (carminative?); or by contraction from the Latin *carmesinus*, purple colour.

The true chemical nature of carmine is still only very imperfectly known. This is partly due to the secrecy which was observed with regard to the manufacturing processes, partly to the costliness of the material, and partly to inherent difficulties of the subject itself.

Carmine is prepared by treating a boiling aqueous decoction of cochineal with alum and a salt of an organic acid, such as bitartrate or binoxalate of potassium. It is essential that the vessel or boiler in which the operation is carried on is made of tin or well-tinned copper, otherwise the brilliancy of the resulting colour is much impaired. Formerly a mysterious influence was ascribed to the kind of weather or atmospheric condition, and it was stated on high authority that good carmine could only be prepared during a bright sunny day. On this account it was erroneously supposed that in England carmine could not be manufactured of the same brilliancy as on the Continent.

According to an old German process, 1 lb. of crushed cochineal is boiled in 1 gallon of water for a quarter of an hour, then 1 oz. of powdered alum is added, and the boiling continued for three minutes longer; after this the vessel is removed from the fire, allowed to stand for some time, and then the clear supernatant liquid is decanted into clean receptacles, which are set aside for several days, when about 1½ oz. of carmine is deposited. An additional half oz. of inferior quality is obtained by permitting the mother liquor again to repose for a length of time.

According to a French method, 1 lb. of crushed cochineal is boiled for fifteen minutes in 10 litres of distilled water, then 30 grms. of cream of tartar are added, and the boiling continued for ten minutes more, 15 grms. of alum are now added and again boiled for two minutes. The liquid is then allowed to settle, and as soon as clear is drawn off in flat glass or earthenware pans, in which the carmine deposits.

Method of Alyon and Langlois.—500 grms. of best crushed cochineal are boiled for twenty minutes with 7·6 grms. of carbonate of sodium in 15–20 litres of water; to this are then added 24 grms. of alum and 4 grms. of cream of tartar, and the liquid allowed to stand quiet until settled. The cochineal dregs fall to the bottom, and after a quarter of an hour the dark-red turbid liquid is poured through a silken sieve, and after a short while through another; the clear liquid is now thoroughly mixed with the fresh albumen of two eggs, and gradually warmed, when the carmine is deposited. By adding a second quantity of albumen to the supernatant liquid, and warming again, a further small quantity may be obtained, which, however, is of an inferior quality.

Method of Madam Cenette of Amsterdam.—2 lbs. of crushed cochineal, of the best quality, are boiled for two hours with 15 galls. of distilled water. Then 3 ozs. of pure nitrate of potassium are added, and in three minutes 4 ozs. of binoxalate of potassium. After having boiled for ten minutes more, the fire is removed and the liquid allowed to settle. The clear liquor is then decanted into shallow bell glasses and set aside for three weeks. At the end of this time the film of mould formed on the surface is carefully removed, without disturbing the liquid underneath, which is then drawn off by a syphon. The deposit of carmine left at the bottom of the vessels, when drained and dried in the shade, is of superior brilliancy and beauty.

[It will be noticed that in this latter method the use of alum is altogether omitted. Inasmuch however as carmine, according to our present knowledge of the subject, has to be considered as an alumina compound, it became desirable to ascertain whether carmine could actually be produced without alum; and accordingly this celebrated process, which for some time back has been copied from book to book, was put to the test. Several trials, in which the above description was followed as closely as possible, produced nothing but a rich crop of mould. It may be therefore assumed, that in communicating or transcribing this method the alum was intentionally or unintentionally omitted.—HUGO MÜLLER.]

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* Joh. Chr. Wiegleb, Die natürliche Magie, vol. i. p. 242. Berlin and Stettin. 1782.

Pure carmine forms an amorphous powder of an intense bright red colour, peculiar to this substance; the tint of which, according to its mode of preparation and its more or less dense condition, varies somewhat. Freshly prepared carmine, when examined under the microscope, appears in the form of irregular aggregations of spheric grains without any distinct sign of crystallization. Carmine is insoluble in water, alcohol, ether, benzol, the essential and fat oils. It is soluble in the stronger mineral acids, insoluble in acetic acid. In the alkalies and in ammonia it is perfectly soluble, forming a deep red or crimson solution. From the ammoniacal solution, when exposed to the air or saturated with acetic acid, the carmine is precipitated with its original properties. Carmine when brought in contact with solutions of the caustic alkaline earth, or the salts of the heavy metals, is more or less readily acted upon and deprived of its brilliant red colour. On dissolving carmine in dilute ammonia there is generally a small quantity of a whitish insoluble substance left behind, which consists of cochineal-wax and fat. Not unfrequently, however, carmine is adulterated with starch, vermilion, and similar substances, which may be readily detected by their insolubility in ammonia. It is otherwise with certain other admixtures, like albumen, casein, and gelatine, which are often added during the process of making the carmine, partly for the purpose of facilitating its precipitation, partly for the purpose of producing a light and flocculent carmine, which for many purposes is preferred on account of its softness and velvety brilliant colour. Pure carmine on being incinerated leaves about 12 per cent. of white ash, which consists of alumina and a little lime. Accordingly, this substance must be considered an alumina compound, most probably of one of the carminic acids; and it is a remarkable fact that alumina, in this combination, becomes soluble in ammonia. It may be mentioned in connection with this that all carminates, whatever their base may be, are soluble in ammonia, and like the carmine are precipitated when insoluble in water from such solution apparently unchanged on carefully saturating the ammonia with an acid.

The mother liquor from which the carmine has separated contains still a very considerable quantity of colouring matter, which may be utilized by neutralizing the liquid and adding freshly precipitated alumina, or by making the liquid alkaline and precipitating with a solution of alumina whilst hot. In this way a crimson-coloured precipitate is obtained which resembles carmin-lake.

The colouring matter retained in this mother liquor is not capable of being transformed into carmine, as might be supposed, by a further addition of alum or the other ingredients mentioned above, for these only will cause a slight precipitate of a crimson colour, but not of carmine. This behaviour obviously leads to the conclusion that one of the necessary elements for the formation of carmine is wanting, or that the colouring matter retained in the mother liquor is altogether different from that which enters into the composition of carmine, and therefore is incapable of forming this compound.

It follows from this that, in order to obtain the best possible result in making carmine, it is requisite to adjust the necessary quantities of the ingredients, and especially of the alum to be used, by previous experiments in accordance with the quality of the cochineal. If too little alum is added, the carmine separates with difficulty; if too much is used, the tint of the carmine is more of a crimson colour, and less brilliant.

Carmin-lake is of a crimson colour, and is produced by precipitating an alkaline decoction of cochineal with a solution of alum, or by treating a simple decoction of cochineal with fresh prepared hydrate of alumina.

Cochineal Scarlet.—This colour is now rarely prepared in the form of pigment, but its application as a dye for wool is of great importance, as its particularly bright and rich tint cannot be obtained by any other means. This colour is the tin compound of the cochineal red, and is obtained by the usual process of dyeing, solutions of the oxides of tin being employed as the mordant. The brightest shades of scarlet are produced by dyeing the wool or silk previously in a solution of annotta, and afterwards in a clear decoction of cochineal, mixed with cream of tartar and the so called "dyer's spirit," which is a mixture of bichloride and tetrachloride of tin. By using a decoction of cochineal in combination with alum and chloride of tin, without annotta, a crimson tint is obtained.

Cochenille Ammoniacale.—Before the introduction of the violet and purple aniline colours, various shades of violet and purple were obtained with this preparation, especially in the dyeworks of France. It used to be prepared in two forms, called *cochenille ammoniacale en tablette* and *en pâte*. The former was obtained by treating 1 part of powdered cochineal with 3 parts of liquid ammonia for four weeks in a well closed vessel, then adding 0·4 parts freshly precipitated alumina, evaporating the mixture in a copper vessel, and finally drying the residue with steam-heat. The latter was prepared in essentially the same manner, without the addition of alumina, and merely evaporating the resulting liquid to a certain concentration. SCHÜTZENBERGER,* who examined this dyeing material, ascertained that on leaving an ammoniacal solution of carminic acid for some time by itself, a peculiar change takes place, which appears to consist in the formation of a compound which contains nitrogen, and which may be considered to be an amide or amido-acid, derived from carminic acid. This carminamide differs from the salt-like derivations of carminic acid by its violet colour being not changed by acids, and by its precipitate with tetrachloride of tin not being of a scarlet but a dark crimson colour.

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* SCHÜTZENBERGER, Comptes Rendus, vol. xlvi. p 47; Ann. de Chim. et Physique, vol. liv. p. 52.

COPPER.—*Cuivre*, French; *kupfer*, German; *cuprum*, Latin. Symbol, Cu; atomic weight, 63·4. This metal has been known from the remotest times. It seems that in the earliest historic times it was extensively employed in the formation of domestic and martial implements, as well as for decorative purposes. *Bronze*, spoken of in the Bible as *brass*, is of very ancient origin. According to modern analysis it consists of copper, tin, and very small quantities of other metals, such as iron, nickel, cobalt, &c. WERNER is of opinion that copper was the first of the metals discovered and extracted by man, both from the physical nature of its ores, and the facility with which it fuses. There is little doubt that the ores of copper were smelted; and, after the metal was obtained, it was subsequently alloyed with tin. The course adopted by the ancient metallurgists for extracting the metals is veiled in obscurity; but, as with most of the products of antiquity, it may be presumed to have been tedious, laborious, and imperfect, beyond the conceptions of those who are now engaged in the business.

The Syrians and Phœnicians were, as appears from various records and the quantity of bronze which they manufactured, large traders in copper; and doubtless, during the search of the latter people for tin in Great Britain and Ireland, they found considerable quantities of the metal. This is the more probable, from the circumstance of many bronze articles being lately discovered in some of the old workings in Cornwall attributed to that commercial people.

Copper seems to have derived its name from *Cyprus*, the island from which the Romans first procured their supply, and which, with Rhodes, continued for a considerable period to constitute the great emporium for the metal, somewhat resembling in this respect the Cornwall and Swansea of Great Britain. It was termed *æs cyprium*, which was shortened to *cyprium*, and ultimately changed to *cuprum*. The Greeks termed copper and bronze indifferently χαλκός.

In the middle ages roofs of houses were occasionally constructed of copper, or covered with it, and laws were usually engraved upon plates of this metal. In the alchemist's nomenclature copper was called *Venus*, not so much on account of the beauty of its lustre, it being accounted an imperfect metal, but from the facility with which it united to and was changed by other bodies.

In England the earlier copper works were situated in the northern counties; at Swansea (where now is the chief manufacture) they sprung up in the early part of last century. Towards the end of that century copper-smelting works existed also in Cornwall; but these were afterwards discontinued, and now the ores of Cornwall go to Swansea to be reduced.

PREPARATION OF THE PURE METAL.—This may be procured by passing dry hydrogen gas over pure oxide of copper, heated to redness in a tube of porcelain or hard German glass. The hydrogen unites with the oxygen of the oxide of copper, producing water, which escapes at the end of the tube. After vapour has ceased to condense upon a cold porcelain surface held to the aperture, the deoxidation is completed; the current of gas is to be maintained during the time the contents of the tube are cooling. The copper is now extracted in a finely-divided state, and may be melted into a globule.

Copper may likewise be obtained by putting 6 parts by weight of oxide of copper, and 1 part charcoal in powder, into a crucible, and subjecting it to a high heat; the metal is obtained as a small button at the bottom. Adding a little borax assists this result.

The pure metal can likewise be obtained from commercial copper, by dissolving it in nitric acid, and adding a little sulphuric acid to the liquid to render it slightly acid; a plate of iron is then immersed in the blue liquor, and the whole left to repose till the solution becomes colourless. The whole of the copper is by that time precipitated upon the plate of iron; it is collected, washed first with dilute sulphuric acid, to dissolve any particles of iron that may be adhering to it; then with water, to remove every trace of the acid; and, finally, dried and fused into a button. When prepared according to the first process, and the quantity of oxide is small, the metal appears in films, which by reflected light show the characteristic red of copper, but by transmitted light are beautifully green.

PHYSICAL AND CHEMICAL CHARACTERS.—Pure metallic copper has a fine red colour, and in this respect it differs from all the other metals, except titanium; it is capable of receiving a good polish; is malleable and ductile, and can be beaten out into very thin plates or drawn into very fine wires. Its melting point is 1200° C., POUILLET; 2204° Fahr. (1207° C.), GUYTON MORVEAU; 2538° Fahr. (1398° C.), DANIELL, showing that it is more fusible than gold, but less so than silver. Liquid copper expands on cooling: if the metal is contaminated with red oxide (dioxide of copper, Cu_2O) it melts at a lower temperature, and solidifies without expanding. In tenacity it ranks next to iron; a wire of the metal 0·787 of a line in diameter sustains a weight of 302·278 lbs., according to GUYTON MORVEAU'S experiments. The specific gravity of copper varies with its state of manufacture, from 8·89 to 8·95; the fused metal has a density of 8·89 to 8·91; unignited copper wire, 8·93 to 8·94; ignited wire, 8·93; and flattened wire or sheet copper, 8·95. The hardness of this metal is not very great, it being scratched by calcareous spar. Its power of conducting heat is a little more than two and a half times that of iron; its specific heat in relation to that of water is as 0·095 to 1; and its linear expansion, when heated from 32° to 212° Fahr., as ascertained by LAVOISIER and LAPLACE, is 0·000017; TROUGHTON says, 0·000019.

During the time copper is kept in fusion it absorbs oxygen, if the fused metal be exposed to the atmosphere, whether in furnace or crucible. At a very high temperature it boils, and if it be exposed to the air in this state it emits fumes, which condense upon cold surfaces into small globules, the nucleus being metallic, and the exterior coating oxide of copper. Exposed to dry air, the metal remains unchanged; but when moisture is present it becomes tarnished, and a coat of oxide and carbonate forms upon it. Heated to redness in an atmosphere of steam, no decomposition occurs; but at a white heat hydrogen is evolved, and oxide of copper formed. Finely-divided copper burns like tinder; and if the flame be intensified by a stream of oxygen gas, it takes fire, and burns with a beautiful green light.

Copper crystallizes in rhomboidal forms, when a large quantity of the metal is allowed to cool; but when precipitated by galvanic action upon a plate of iron, the crystals are octahedral. A dilute solution of a copper salt left in contact with wood often deposits cubical and octahedral crystals. The glittering spangles in the *avanturin glass* made some time ago at Murano, near Venice, and which was highly prized for decorative purposes, have been proved by WÖHLER to consist of crystals of metallic copper.

Nitric acid dissolves copper, giving rise to a nitrate with disengagement of nitrogen dioxide, which, on coming in contact with air, is converted into nitrogen tetroxide; dilute sulphuric acid has no action upon it; but concentrated oil of vitriol, at a boiling temperature, forms with it sulphate of copper, a part of the acid being decomposed into oxygen, which unites with the metal, and sulphurous acid, which escapes.

Hydrochloric acid dissolves with difficulty compact masses of copper; but if they be finely divided, solution is effected with facility.

Copper is a dyad metal in its most stable salts, univalent in its cuprous compounds.

ORES OF COPPER.—These form a numerous class of minerals, the recognition and distinction of which is extremely important. Below is given a more or less detailed description of each of them, as well as of other minerals containing copper which have hitherto been met with in quantities too small to constitute them an *ore*, but which still should be known, as often pointing to the presence of the other minerals in larger quantities.

LIST OF COPPER MINERALS.

	General Composition.
* Native copper,	Metallic copper.
* Red copper,	Sub-oxide.
* Chalcotrichite,	Do.
* Black copper,	Protoxide.
Tenorite,	Do.
* Malachite,	Carbonate.
Azurite,	Do.
Atacamite,	Oxy-chloride.
Cyanosite,	Sulphate.
Chrysocolla,	Silicate.
Dioptase,	Do.
Liebethanite,	Phosphate.
* Copper glance,	Sulphide.
* Purple copper,	Sulphide of copper and iron.
* Copper pyrites,	Do.
* Grey copper,	Sulphide of copper, antimony, and other metals.
* Bournonite,	Sulphide of copper, lead, and antimony.
Whitneyite,	Arsenide.
Copper mica,	Arseniate.
Oliverite,	Phospho-arseniate.

* An asterisk marks those which at present supply copper in a large way.

Native Copper.—Copper is one of those metals which are found in nature in a metallic state. Native copper is thoroughly tough; it commonly occurs in thin plates, squeezed out as it were into dendritic forms; but at several places, especially round Lake Superior, thick masses of it have been discovered and raised. It occurs also in crystals of the cubical system. It is often associated with native silver. Its occurrence in the native form is accounted for by presuming that the sulphate of copper which would result from copper pyrites in the presence of moisture has been exposed to an electro-chemical action, by which the metal has been deposited. It has also been supposed to be formed by the deoxidation of cuprite.

Red Copper or *cuprite;* in French, *cuivre oxydulé;* in German, *kupferroth* or *rothkupfererz.* Composition, Cu_2O, having 88·8 per cent. of copper. It is chemically known as red oxide, or dioxide of copper. It has a blood-red or cochineal-red colour, and a lustre that varies from sub-metallic and adamantine to earthy; some specimens are partly transparent. It is brittle; the hardness from 3½ to 4, the streak being of a brownish red, and sometimes shining; the specific gravity is 6. It crystallizes in the cubical system, the usual form being the octahedron, with an octahedral cleavage. Before the blow-pipe it fuses, and on charcoal in the reducing flame may be reduced to the metallic state. Red copper occurs in most copper localities, though by no means often in any large quantity.

Chalcotrichite.—This mineral has the same composition as the last, and is of the same cochineal-red colour; but it belongs to a different crystalline system—the trimetric. It usually occurs in a fine capillary or fibrous form.

Black Copper or *Melaconite*; in French, *cuivre oxyde noir;* in German, *kupferschwartz.* Composition, CuO, being 79·8 per cent. of copper; but it commonly has impurities, both earthy and metallic, which lower the percentage. It is black in colour; occurs amorphous, sometimes in botryoidal masses, sometimes in a powdery state; the lustre may be either sub-metallic or earthy. Hardness of the less friable specimens, 3. Its behaviour before the blowpipe is similar to that of cuprite, first fusing, and then, with reducing agents, giving a globule of copper. It is not uncommonly found in copper mines, being doubtless a product of the decomposition of other copper minerals; near Lake Superior it has been raised in large quantities.

Tenorite.—This is a mineral of the same composition as the last (CuO). It occurs in small hexagonal crystals of a dark steel-grey colour. It is found in the craters and in the lava of Vesuvius, having been deposited from the vapour of the eruptions.

Malachite, or *Green Carbonate of Copper.*—This mineral first became known to the general public in 1851. In the Great Exhibition of that year exceedingly magnificent specimens of it, used for inlaying sideboards, cabinets, &c., were displayed in the Russian department. Its fine polish and varying depth of colour give an admirable effect in such work; later it became a great favourite for such ornaments as bracelets, brooches, &c. Composition, $CuCO_3 + CuH_2O_2$, which would be of CuO 71·9, of CO_2 19·9, of H_2O 8·2; analyses give about 56 per cent. of copper.

The colour is bright green of various shades, which generally are in concentric bands; the streak is of a green paler than the colour. The lustre varies from adamantine or vitreous on the one hand down to earthy; it is sometimes translucent, more usually opaque. Hardness, 3½ to 4; specific gravity, 3·7 to 4. It crystallizes in the monoclinic system, but it more commonly occurs amorphous, in mamillated, stalagmitic, or in stalactitic forms. These, as well as the banded appearance before described, show how malachite has been deposited, namely, from a solution of copper from above, carbonic acid-bearing water having acquired the metal from other copper minerals and brought it down to be deposited in the rock cavities. Heated in a close tube it yields water and blackens; before the blowpipe on charcoal it fuses, and is reduced to metallic copper.

The chief localities for malachite are the Ural Mountains and South Australia, which latter country has afforded and is affording great quantities to the smelter.

Azurite, or *Blue Carbonate of Copper*, or *Chessylite;* in German, *kupferlazur.*—This, like the last mineral, is a hydrated carbonate of copper, but the proportions of the elements are somewhat different; its formula is $2(CuCO_3) + CuH_2O_2$, which gives of CuO 69·2, of CO_2 25·6, and of H_2O 5·2 per cent. The colour is bright blue, of a shade somewhat darker than azure; the lustre is vitreous; it has various degrees of transparency. It is brittle; the hardness varies from 3½ to 4¼; the streak is of a paler blue than the surface colour. Specific gravity, 3·5 to 3·8. It crystallizes in the monoclinic system. Before the blow-pipe azurite behaves like malachite. Azurite has been obtained in smelting quantities at Chessy in France, and, later, from South Australia; copper of a good quality resulted.

Atacamite.—Native oxychloride from Peru and Chili. Analyses give 15 to 16 per cent. of copper. This mineral is more or less translucent. Its colour is of various shades of green, and its streak apple-green; its lustre is from vitreous to adamantine. Hardness, 3 to 3½; specific gravity, 4 to 4·3; when crystallized it is found in forms belonging to the trimetric system. Before the blow-pipe it gives a blue tinge to the flame, and on charcoal gives a globule of copper. This mineral has only occasionally been worked as an ore of copper.

Cyanosite.—This is the native sulphate of copper, or blue vitriol; it is produced in nature by the oxidation of the sulphides.

Chrysocolla; in German, *kieselkupfer.*—Native silicate of copper; the percentage of copper varies from 45 down to 20 or less. This ore is of a turquoise-blue colour, inclining to green, sometimes translucent; the streak is white. Hardness, 2 to 3; specific gravity, 2 to 2·2. It does not crystallize, but is found massive or in crusts. Before the blow-pipe it is infusible, but with soda or charcoal gives a globule of copper.

Dioptase is another silicate with the elements in somewhat different proportions. It is of a vitreous lustre and translucent, of an emerald-green colour and green streak. Hardness, 5; specific gravity, 3·2. crystalline system, hexagonal. Before the blowpipe it acts as does chrysocolla.

Liebethanite.—This is a hydrous phosphate of copper; it is of resinous lustre and olive-green colour. Hardness, 4; specific gravity, 3·7. It crystallizes in the trimetric system.

Copper Glance, or *Red Ruthite;* in French, *cuivre sulfuré;* in German, *kupferglanz.*—Composition, Cu_2S, containing from 75 to 79 per cent. of copper. This is a very valuable ore on account of its richness in copper, but it is not so widely disseminated as other sulphur compounds of the metal to be noticed below. It has a metallic lustre and a dark grey colour, which is apt to change by tarnishing to an iridescent blue or green; the streak is the same as the original colour, and sometimes shining. Its hardness is 2½ to 3; the specific gravity 5·5 to 5·8. The crystalline forms are peculiar and recognizable; they are modified prisms of the trimetric system, often in twinned combinations, which are sometimes of a stellate arrangement. Before the blow-pipe it fuses, and on charcoal copper may be reduced from it.

Purple Copper.—This is also called erubescite and bornite. In French, *cuivre pyriteux hépatique panache;* and in German, *Buntkupfererz.* Composition, $2Cu_2S + FeS$, the copper being about 60 per cent. of the whole. It is of a metallic lustre, and a colour which is somewhat brownish coppery red; usually its surface is varnished purple and blue; the streak is greyish black, slightly shining. It has a hardness of 3, and a specific gravity which varies from 4·4 to 5. It crystallizes (though seldom) in the cubical system. Before the blowpipe it fuses to a magnetic globule. It commonly occurs in company with the other sulphur bearing ores of copper, and is often an important ore itself.

Copper Pyrites.—In French, *cuivre pyriteux;* and in German, *kupferkies.* Composition, $CuFeS_2$ or Cu_2S,Fe_2S_3, the copper being from 32 to 34 per cent. It is of a metallic lustre and a brass yellow colour, which, as in the case of the last mineral, though not so commonly, tarnishes and becomes iridescent. The streak is greenish black, a little shining. The hardness is from 3½ to 4, the specific gravity 4·1 to 4·3. It crystallizes in the pyramidal or dimetric system, in forms which closely resemble forms of the cubical system; it often takes hemihedral forms. Before the blowpipe it fuses to a magnetic globule, while with fluxes it easily yields a bead of the metal. This is the ore of copper most commonly met with in Britain, and indeed, taking the world over, the principal source of the metal.

Grey Copper, also called *tetrahedrite.*—In French, *cuivre gris;* in German, *fahlerz.* In composition it is a variable combination of sulphur with copper, antimony, arsenic, lead, silver, and other metals, the copper varying from 25 to 40 per cent. It has a metallic lustre, and is of a steel-grey or iron-black colour. Hardness, 3 to 4½; the variableness of its composition telling upon this also. Specific gravity, 4·5 to 5·11. It crystallizes in the cubical system, generally in hemihedral forms, often twinned. Before the blowpipe it gives off antimonial and arsenical fumes, and with carbonate of soda yields metallic copper. As a source both of copper and of silver this mineral is of much value.

Bournonite, sometimes called by the Germans *radalerz*, is a sulph-antimonate of copper and lead. It contains 12·7 per cent. of copper. It is of metallic lustre, and a steel-grey colour; hardness, 2½ to 3; specific gravity, 5·7 to 5·9. It crystallizes in the rhombic system, the crystals often crossing each other in such a way as to give a radiated form to the mass, like the spokes of a wheel, with a cog-like circumference.

Whitneyite is an arsenide of copper, containing about 88 per cent. of copper and 11 of arsenic. It has a metallic lustre and reddish-white colour. Hardness, 3½; specific gravity, 8·4.

Copper mica, or *chalcophyllite*, a hydrous arseniate of copper. It is of vitreous or else a pearly lustre, and greenish colour. It crystallizes in the rhombohedral system in tabular crystals, with perfect cleavage of the basal plane.

Oliverite, sometimes called wood arsenite, is a hydrous arseniate and phosphate of copper. It is of adamantine or vitreous lustre and olive-green colour. Hardness, 3; specific gravity, 4·1 to 4·4. It crystallizes in the trimetric system.

These minerals, it must be understood, occur associated not only together, but also with various others, and especially with those non-metallic minerals which form what is called the *gangue* or vein-stuff that makes up the largest portion of the mineral vein. In copper-bearing lodes the most frequent of these minerals are quartz and fluor-spar, but quartz in general exceeds all the others in quantity. In mining, it becomes necessary to raise much of this *gangue* with the ores, so much indeed, that even after separating it as much as possible in the way to be described immediately, the percentage of copper in the ore that goes from Cornwall to the smelters is but from 5 to 7.

Mechanical Preparation of the Ores.—After the ores are extracted and brought to the surface, they are sorted, and are thus rendered more eligible to the purchaser for smelting.

The dressing to which the copper ores of Cornwall and Devon are subjected is mostly conducted in the following manner:—

The first operation is to separate the larger pieces of ore, called *spalling stuff*, which is for the most part of a good quality; the next batch is called *picking rough*, and is composed of lumps about the size of a cubic inch or more; it is removed by riddling the ore left, after selecting the large pieces, through a stout wire-gauze, the meshes of which are about three-quarters of an inch square; what passes through the riddle is denominated *shaft small*. Having done this, the spalling stuff is broken, either by flat-faced heavy hammers or by rollers, into pieces about the size of the second batch above mentioned, and assorted; pure pieces of ore, called *prills*, are obtained; and the other matters, which are again crushed with the *pickings*, are selected, and the better portions set aside with the prills of pure ore, which are ready for sale.

The remaining batches are now in great measure freed from gangue, by grinding, and afterwards washing with water, either in an inclined plane, or in a vessel with a wire-gauze bottom, in order to remove the foreign particles from the heavier metallic substances.

These processes are designated *jigging* or *buddling*, each of which promotes the desired effect, by causing the materials to deposit according to their relative specific gravity. When the most part of the impurities have been removed, and the ore is deemed sufficiently dressed for the smelter, it is made up into parcels or heaps ready for sale.

Copper-smelting at Swansea.—The process which will be described in detail under this heading is carried out to by far the largest extent in Swansea and its vicinity, a locality which surpasses any other in the world in the extent of its copper works. The same process is followed in Lancashire, and it has fairly been called the "English method" of copper smelting. To Swansea comes the ore which has been raised in Devon and Cornwall, as well as some that has been produced in Ireland, and large quantities of various ores from abroad.

Several circumstances have combined to render Swansea an emporium for copper—its comparative nearness to Cornwall and Devon, the great copper-mining counties; an easy approach for coasting and other vessels, by which material can be conveyed at a low rate; the adjacent coalfield to supply the works with that which is to them a first necessity, fuel; a return freight for coal to Cornwall for the mines, &c.

Classification of the Ores.—These vary both in percentage of metal and in composition, according as the supplies of them arrive from various countries. Of all it may be said that they are sure to be accompanied by a large amount of *gangue* (that is to say, non-metallic mineral substance—vein-stone), which is commonly silicious in composition. Five classes are distinguished by the smelter, which must be either differently treated or carefully mixed.

First Class.—Comparatively poor ores, containing copper pyrites and a considerable proportion of iron pyrites; in these the percentage of iron (from the two minerals) is of course large; copper is present to the extent of from 3 to 15 per cent.

Second Class.—Richer ores of like composition to that of the last class; they may contain from 15 to 25 per cent. of copper.

Third Class.—Copper pyrites chiefly, little of iron pyrites, but with some amount of other copper minerals, as of the oxidized ores.

Fourth Class.—Oxides and carbonates of copper, with little of the sulphides; the percentage of copper from 20 to 30.

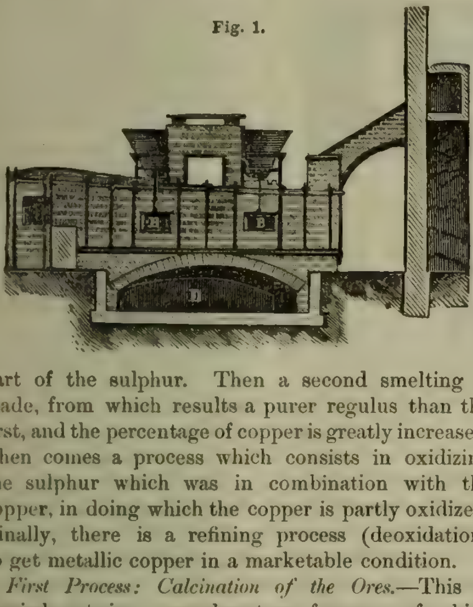
Fifth Class.—A product of ores which have already undergone some metallurgical process, such as calcination and fusion. It then constitutes a *regulus* or *matt;* rich in copper (yielding often as much as 50 per cent.), and free from earthy ingredients. It is imported from abroad for further smelting in England.

Ores of the first three classes are mixed for treatment, so as to contain from 8 to (at the most) 16 per cent. of copper. Those of the two last classes are brought in at stages of the process.

General Sketch of the Processes.—The reader should have a general idea of the chemical changes that take place in this somewhat elaborate system of metallurgy before loading his mind with the details.

The sulphurous and iron-bearing ores are first partially oxidized, the sulphides being turned partly into sulphates, partly into oxides; then they are melted down without any oxidizing influence, when there results a substance which is a sulphate of copper with some sulphide of iron, and above is a clay which consists of the earthy siliceous materials, combined with the rest (the greater part) of the iron. The mixed sulphide thus produced (which is called a regulus) is then roasted, so as to oxidize the remainder of the iron and get rid of the greater part of the sulphur. Then a second smelting is made, from which results a purer regulus than the first, and the percentage of copper is greatly increased. Then comes a process which consists in oxidizing the sulphur which was in combination with the copper, in doing which the copper is partly oxidized. Finally, there is a refining process (deoxidation) to get metallic copper in a marketable condition.

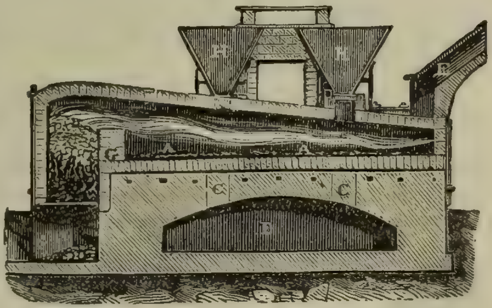
Fig. 1.



First Process: Calcination of the Ores.—This is carried out in a reverberatory furnace, of which Fig. 1 gives an elevation, Fig. 2 a section, and Fig. 3 a plan.

The bed, represented in the figures by A A, is of an elliptical form, truncated at the extremities of its greater axis. The walls, however, deviate from the elliptical outline near the openings, for the purpose of facilitating the removal of the charge. The furnace is constructed of firebricks set endwise in a bed of refractory fireclay; its length is about 16 feet and its breadth 13½. Beneath it is a vault, D, serving as a receptacle for the roasted material, which is drawn out by the furnace-men through the openings, C C, behind the working doors, B B. The arch of the furnace, the mean height of which is about 2 feet from the bed, contracts rapidly in height towards the flue holes, E, by which the gases evolved from the combustible products, both the fuel and the sulphur of the ore, pass off to the chimney. F is the fire-grate and G the bridge. Air is admitted into the furnace by means of openings, such as O, made near the fire, and capable of being closed at pleasure. The projections between the doors are intended to prevent accumulation of ore in places where the rake could not readily reach it.

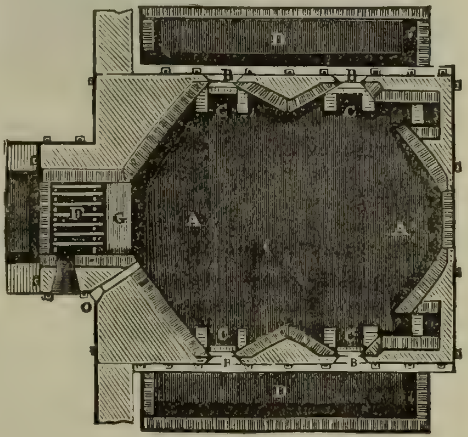
Fig. 2.



In other forms of the furnace there is a channel made in the bridge, G, which opens outwardly, for the purpose of forming an equalized current over the whole of the hearth. On this account, and also because the current is heated in passing through the bridge, this construction is more effectual than the other.

H H are two large sheet-iron hoppers, with sliding doors at the bottom; into these the ore to be roasted is put, and when required it is let into the furnace by drawing back the slides at the bottom. Exteriorly the furnace is bound with strong upright and horizontal bars of iron, to give it firmness.

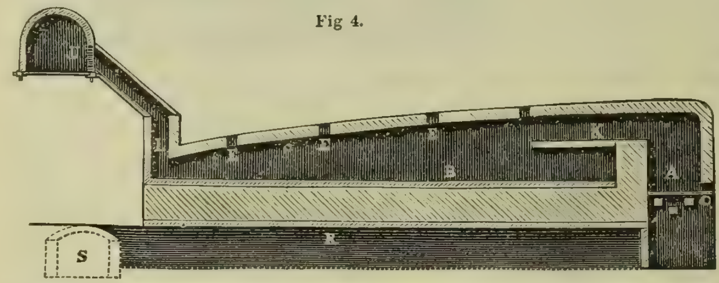
Fig. 3.



Some furnaces are made longer in proportion than the one figured, having three, or even four openings on each side. Such a furnace is shown in Figs. 4 and 5: A is the furnace, the bars of which rest upon the topmost two of the transverse rods beneath it; the lowest rod serves as a fulcrum for a crowbar in clinkering the fire; B is the hearth; C, square openings in the hearth through which the burnt ore is raked into the space, R, beneath the furnace. Over each of these openings is a door in the side (as in Figs. 1 and 3), through which the workman introduces his rake; the burnt ore is afterwards removed through the gate, S. The hoppers containing the raw ore are placed over the openings, E E E E, through which the charge is supplied as required. The raw ore is protected from the first fierce action of the flame by an arch, K, which extends across the furnace. The small flue, L, communicates with the main flue, U, leading to the chimney shaft.

The bars of the furnace, which are usually from 4½ to 5 feet in length and about 3 inches square, are placed at a considerable distance apart, and pieces of slag or bricks thrown upon them. Upon these the fire is made, and as the carbonaceous matter is consumed the earthy portion fuses and forms clinkers; but meeting the upward current of cold air it contracts, and numerous fractures sufficient for the passage of the current form in it. As this clinker accumulates the attendant removes a portion from the bottom, but retains a bed of from 12 to 18 inches in thickness upon the bars. By this means none of the coal is lost; the bars of the grate will serve for an almost indefinite period, as the mass of clinkers preserve them from burning, and the fire burns well. Openings or holes are made in the clinkers to give draught, and produce what is necessary in the roasting of the ore, namely, a sheet of flame over the hearth or bed. As the stream of air rushes through the grate and fire it is deprived of oxygen by the ignited coal, and the gases evolved over the bridge are nitrogen and carbonic oxide; scarcely any carbonic acid is produced during this part of the combustion. The air-holes represented in Fig. 3 now begin to act their part, for as the fresh stream of air rushes in through them, and meets with the half-consumed carbon at an elevated temperature, a fresh combustion takes place, the carbonic oxide takes fire, a flame is produced along the hearth of the furnace, and carbonic acid is formed.

Fig 4.



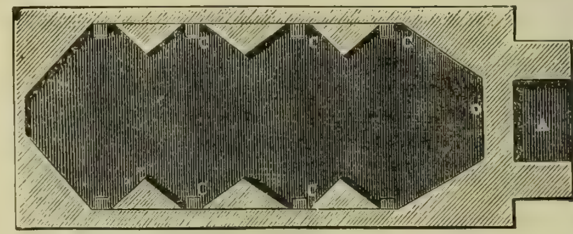
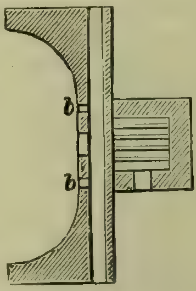


Fig. 5.

But it must be remembered that not only is atmospheric oxygen wanted to consume the fuel and produce the necessary heat, a surplus also is required to oxidize the sulphurous ore. An ingenious plan adopted in some furnaces tends to effect this more completely; fig. 6 is a horizontal section of the fire-bridge; and shows a transverse channel through the bridge into which air flows from each end, and enters the furnace by the opening represented from *b* to *b*.

Fig. 6.



The furnace being already hot (for the action is kept up continuously) the charge, which generally amounts to about three or three and a half tons, is let into the furnace by removing the plates which cut off the communication between the hoppers and the interior. As soon as the whole is introduced the plates are again restored, and the ore spread evenly on the sole of the furnace by means of iron rakes working through the doors. This being done the doors are closed, the fire is replenished with the proper allowance of coal, and the draught through the clinkers established by abstracting a few of them if required, or loosening them by means of an iron rod made in the form of a pick at the end, the fire-door itself being closed.

The fire now begins to exert its influence upon the ore, but much care is required in its management; the object is to decompose sulphides as much as possible, and produce oxides instead. To effect this the temperature should not be too elevated, or the sulphides present will fuse and form a solid mass, offering only a small surface to the flame, and therefore rendering the roasting imperfect, and entailing much trouble besides, for the fused matt, as the sulphide is called, will adhere to the walls of the furnace.

The precaution of keeping the fire at a moderate working temperature is to be attentively observed during the first six or eight hours of the roasting, that is, as long as the ore contains an excess of sulphur and other volatile bodies; after this, to the end of the operation, the heat may be increased as the tendency of the charge to agglutinate becomes less. At first the aqueous vapours and some sulphurous acid are eliminated, the latter increasing in abundance during the first two hours, upon which the doors are opened, and a fresh surface presented to the flame by furrowing the charge in parallel lines with a long iron tool, called a *rabble.* Then the fire is again charged, and the combustion of the ore allowed to proceed without interruption.

This work, rabbling the ore with rakes and bars, and of firing, takes place at the end of every two hours, till as much of the volatile products as can be expelled by the heat is driven off and oxygen substituted. This happens in from twelve to twenty-four hours; but towards the end of the calcination the fire is so urged, that when it is time to draw the charge the furnace is at its highest degree of heat. The doors are now opened, and iron plates which cover the openings, C C, Figs. 2 and 3, removed, in order that the calcined mass may be raked through them into the vault, D (or R, Fig. 4), whence, on cooling, it will be removed in barrows to undergo the ensuing process. This part of the operation is the most laborious and injurious to the health of the workmen, for, in addition to the great heat, they have to endure a worse evil in the shape of sulphurous and sulphuric, and often arsenious, acids, from the sulphur, &c., which was not expelled whilst the ore was in the furnace. The calcined ore should have a brownish black colour.

Immediately the calcined batch is cleared out, another is introduced and the evolution of aqueous vapours and sulphurous acid gas at once recommences. The material is spread out evenly, and after an interval of about fifteen minutes, during which the heat of the furnace will have fallen to the proper working pitch, the firing is renewed, and operations are again proceeded with as already recounted. Each furnace is watched by two men.

To save fuel the furnaces are now usually supplied with gas from one of SIEMENS' producers (see FUEL), and a fire bridge is placed at each end so that the flame can be sent either way by reversing the draught.

Chemical Reactions of the First Process.—M. LE PLAY gives the following numbers as representing the average result of the calcination: the first list is an analysis of the original or crude ore; the second, of the calcined ore:—

		Total weight.	Centesimal weight.
Crude Ore.	Oxide of copper isolated or combined,	3·2	·374
	Copper pyrites,	194·2	22·710
	Iron pyrites—bisulphide of iron,	191·9	22·442
	Various sulphides,	8·7	1·001
	Oxide of iron,	5·2	0·608
	Other oxides,	2·3	0·269
	Quartz and silica,	294·4	34·428
	Earthy bases,	16·0	1·871
	Water and carbonic acid in combination,	4·2	0·491
	Oxygen consumed,	135·0	15·805
	Products:—	855·1	100·000
Calcined Ore.	Oxide of copper,	46·2	5·401
	Copper pyrites,	96·0	11·228
	Bisulphide of iron,	95·8	11·226
	Other sulphides,	5 2	0·600
	Ferric oxide,	100·2	11·718
	Other oxides,	5·2	0·608
	Sulphuric acid in combination,	9 5	1·108
	Quartz and silica,	294·4	34·408
	Earthy bases,	16·0	1·874
Gaseous products,	Sulphurous acid,	182·5	21·338
	Water and carbonic acid,	4·2	0·491
		855·1	100·000

The ore does not lose much in weight, the quantity of oxygen absorbed in great part making up for the diminution of the sulphur; of the sulphur itself about half is evolved. It appears, then, that the chief change is a decomposition of a considerable portion of the copper and iron pyrites, and a consequent formation of oxide of iron, and of a less proportion of oxide of copper. This change, however, is not made at one step: it would seem that *sulphates* of the two metals are first formed, which, by a continuance of the heat, are made to lose their sulphuric acid. The oxide of copper spoken of as resulting is the suboxide; of the iron oxide, the greater part is sesquioxide, but Dr. PERCY has proved the presence of magnetic oxide as well.

The volatile results of the roasting in the calcining furnace are therefore:—

Aqueous vapour,
Sulphurous acid,
Sulphuric acid,
Arsenious acid and arsenical vapours,
Fluoride of silicon and other volatile compounds of fluorine,
Solid matter, mechanically conveyed by the draught into the flue,
Carbonic acid, &c.

All these arise from the combustion of the fuel and ore; the water is formed by the oxidation of the hydrogen of the coal, as well as by the expulsion of the moisture in the mass. It is this which, acting on the sulphurous acid arising from the sulphur in the presence of the oxygen in the furnace, gives rise to sulphuric acid. The arsenic and its compounds are contained in the ore, and are expelled as such; but the former undergoes combustion in part, and forms arsenious acid. By the action of the silicious gangue upon the fluoride of calcium, fluoride of silicon is produced. Hydrofluoric acid is also generated, as is evidenced by the action of the gases upon glass. DUMAS accounts for its occurrence by the supposition that fluoride of arsenic is formed, which, in contact with the vapour of water, becomes converted into arsenious and hydrofluoric acids.

All these vapours pass off into the atmosphere, and from their enormous quantity, and their destructive influence upon vegetation, cause serious damage to the surrounding district. The constant evolution into the air of such immense volumes of poisonous gases must also be hurtful to animals. The face of nature in the vale of Swansea bears indelible traces of the ravages of the vapours. It is also to be regretted that such a vast quantity of sulphur should thus be wasted. Many exertions have been made to condense the poisonous fumes, in order both to prevent nuisances and to utilize the valuable products. The following is the plan adopted by SPENCE with considerable success:

In his first arrangement (Figs. 7 and 8) the calciner had a flat bed, A, for the ore, 40 feet long by from 6 to 9 feet in breadth; beneath this bed the flues, B, from the fire, C, traverse the whole length of the furnace, finally making their exit to the chimney shaft at D. The ore is supplied to the furnace by the hopper, E, and after parting with most of its sulphur is transferred by slices towards the fire-end of the roaster, and a fresh charge is introduced; by the time it reaches the far end of the furnace it is thoroughly calcined, and is drawn out into an iron truck. Sufficient air to convert the sulphur into sulphurous acid is admitted at this end. The sulphurous acid gas passes into the vitriol chamber by the flue, F.

Fig. 9 is a modified form of the same furnace. Here the calcining furnace and the smelting furnace are combined. As the ore which leaves the calciner at a red heat is so far ready for smelting, and at the same time the waste heat of the smelting furnace is sufficient to effect calcination, much fuel is saved by joining the two furnaces.

K is the door of the smelting furnace; B B the flue conveying the waste heat under the calcining bed, A A; it passes by C into the shaft. The raw ore is supplied from the hopper, E; after being burnt it drops into the smelting furnace through the tunnel, F. The sulphurous acid is conveyed by G over the nitre pot, H, into the vitriol chamber, I.

Fig. 7.

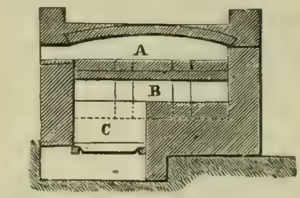
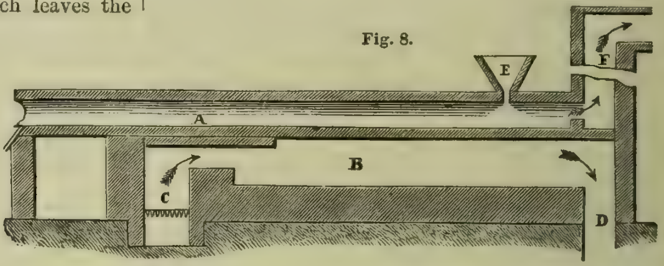
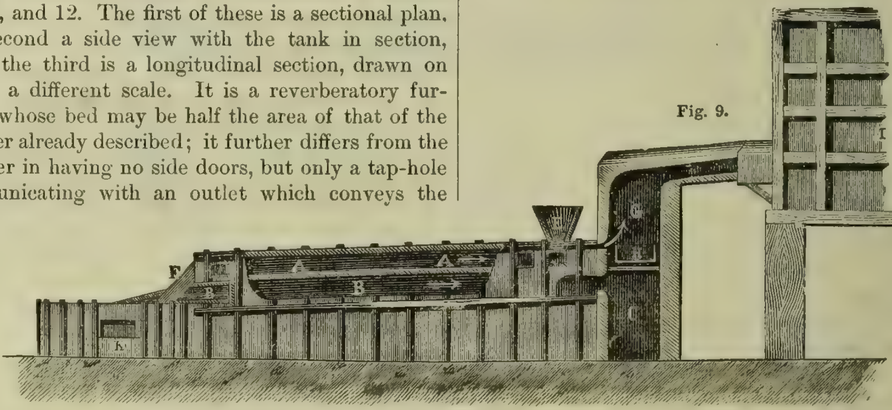


Fig. 8.



Second Process: Melting of the Calcined Ore.—The calcined ore is next melted with the slag from the *fourth process* (presently to be described), which slag is called *metal slag*.

Fig. 9.



The furnace employed is represented in figures 10, 11, and 12. The first of these is a sectional plan, the second a side view with the tank in section, while the third is a longitudinal section, drawn on rather a different scale. It is a reverberatory furnace, whose bed may be half the area of that of the calciner already described; it further differs from the calciner in having no side doors, but only a tap-hole communicating with an outlet which conveys the melted product into a proper recipient. In the following description the letters refer to the first two figures only, figs. 5 and 6. A is the bed or hearth where the charge is elaborated; this inclines towards the outlet already mentioned, so as to form a kind of basin; the bed is formed of alternate layers of sand and *metal slag;* B shows the furnace bars (which cover a much greater proportional area than do those of the calcining furnace), C, the fire-door, while the working door of the furnace is opposite to the fire. E is the door of the outlet, but this is securely closed during the period of working the charge. F, F, F are sand moulds, into which the slag is raked out; H, in the side view, is the hopper through which the calcined ore is introduced, the materials constituting the succeeding charge being put there whilst one is being worked off; G is a tank kept full of cold water by a supply-pipe, *a*, and emptied by another leading from it at the bottom. In this tank a frame of wood or iron is immersed, the bottom of which is composed of a stout wire gauze, the whole being connected by ropes or chains to a winch, W, which serves to lift the frame out of the tank when necessary. K denotes the chimney, which exercises a greater influence upon this than the preceding furnace. This is necessary, because the heat required in this second operation is much higher than in the first. The fire is constructed upon a mass of clinkers. The charge for this furnace consists of about 21 cwts. calcined ore, and sometimes fresh ore, of the sort that contains less sulphide of iron (of the third class), is added; sometimes larger furnaces and greater quantitities are employed. All this is introduced through the hopper; *metal slag* to the extent of 3 or 4 cwts. is added through the door at the end; the object of this last is two-fold—to render the whole more fusible, and to obtain the copper remaining in that slag. The man attending the furnace fills the hopper during the fusing of the charge, and has all the materials ready, so that when the furnace is tapped, a new charge is instantly let in, that no heat be lost. As soon as the charge from the

Fig. 10.

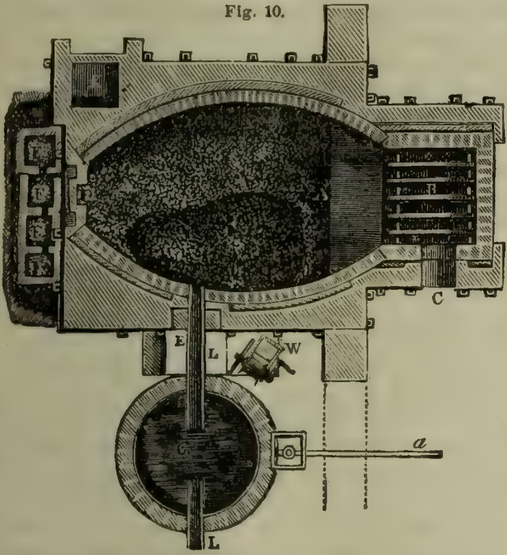
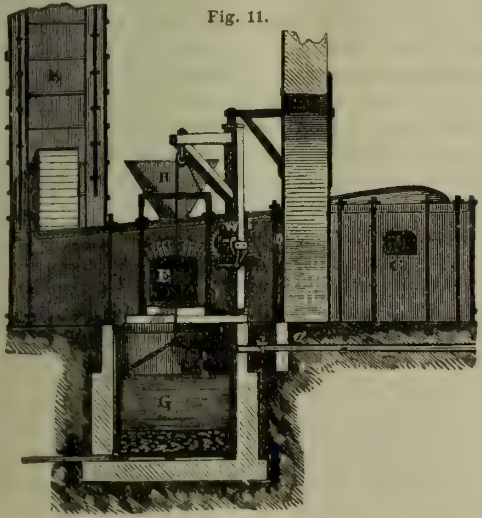
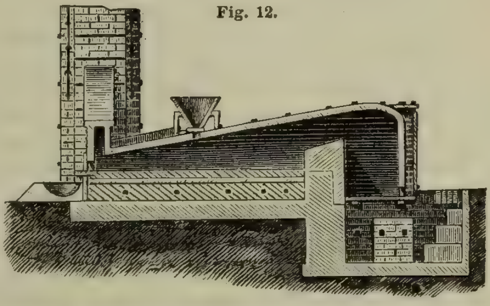


Fig. 11.



hopper is introduced into the furnace, the attendant spreads it as quickly as possible upon the bed or hearth, and then throws in interspersedly the pieces of slag. When all has been added the door is carefully closed and made secure by luting, as also the side opening; the furnace-man then replenishes the fire, and refreshes the draught by removing some of the clinkers, and opening the crevices with the pointed iron. The charge is unmolested for three hours and a half, the interior being observed from time to time, to watch the fusion. Fresh fuel is thrown on at the end of an hour and a quarter, or less, as deemed requisite; the quantity being proportioned to the allowance for the working of each charge. In half an hour after the spreading of the ore on the hearth of the furnace the slag begins to fuse, and in a very short time it forms liquid channels, or little lakes, in the mass. Soon after, the fused mass extends over the whole hearth, from the combination of the iron and silica present into a very fusible silicate of iron. As the quantity of liquid matter increases, it becomes agitated from the evolution of sulphurous acid, produced by the oxidation of the sulphide of iron, a silicate of iron being formed instead. Fluoride of calcium also brings about the fusion more readily, and the decomposition of this compound in the presence of silica, by which fluosilicic acid gas is disengaged, favours the intimate mixture of the materials, and aids in the expulsion of the arsenic. At the end of about five hours the whole of the charge is melted, except those portions of slag which may remain at the sides of the furnace, and gas ceases to be evolved. The furnace-man now opens the door, and by a long rake rabbles the whole charge, by which means the unmelted portions are brought into contact with the fused mass, and thereby dissolved. He now urges the fire to its highest heat, which is maintained in that state for about half an hour. During this time the moulds for the slag are being prepared by spreading the sand evenly, and then digging out a form of a mould. Then the slag is raked out through the end door into these moulds. When this is done the process of charging and melting is repeated, and so on until, after a lapse perhaps of twenty-four hours, enough of regulus has accumulated to fill the bed. Then the tap-hole is carefully opened to draw off the fused matt or regulus, which flows into the water tank, and in doing so becomes granulated; afterwards the box G, into which it had fallen, is raised by the winch, and the granulated substance is removed. In some works granulation is omitted and the regulus is run into moulds.

Fig. 12.



Some regulus is attached to the slag in the first of the sand moulds; this is carefully separated; a little also remains in the form of buttons with the mass of the slag, but if the operation has been conducted with care the loss is not great. The amount depends on whether the slag has been kept (by judiciously proportioning the supply of *metal slag*) to the proper consistency; for if it be too thick beads of regulus will remain in it, if it be too thin some of the regulus will be drawn out with it in the skimming. The products, then, of this second process are a regulus of sulphide of copper with some sulphide of iron, called *coarse metal*, having about 35 per cent of copper, and the slag, called *ore-furnace* slag. This slag is thrown away, and it is the only product of the whole series of operations which is entirely lost; the loss, by copper contained in it, should be but small, but still it is appreciable, for in most of the refuse masses small globules of the copper sulphide can be seen. Mountains of discarded slag may be seen accumulated near some of the large smelting-houses, and conveyed from the works by rail and steam, at a cost to some of the large works of from £3000 to £5000 annually. Great quantities are used for roads and walls.

Every furnace is looked after by two men, each attending twelve hours, and the operations never cease night or day during the week till Sunday, from which time till Monday morning following all the furnaces remain uncharged. They are not, however, allowed to cool, but one or two men maintain the fires, so that they may be ready to receive a charge as the first thing requiring to be done at the beginning of the week. The night-shift is taken by the men alternately. To those who have been working at these furnaces for some time very few directions need to be given, so long as the ore operated upon remains of a uniform composition, as well in metal as in slag, for they have in that case only to add the proper quantity of fluxing matter at once, and proceed as just detailed; but any alteration in the nature of the ore, whether it be in the quantity of metals or in the amount of gangue, causes a derangement, which must be righted by a complete quantitative analysis of the ore.

When poor and rich ores are at hand, the easiest course, and that which is usually adopted, is to mix them in quantities calculated to produce a compound of the same mean composition as that which is generally operated upon; but if the materials cannot be thus regulated, the flux must be apportioned to produce the desired effect. Much care is taken to avoid having an excess of scoria, lest too much copper should be mechanically retained by it, and a loss sustained. For this reason fluoride of calcium is not used, except it is considered that the gangue is difficultly fusible; and the fused scoriæ from the succeeding operations are not on these occasions added at once, but only in successive small portions at a time, followed by a rabbling, till the whole contents have arrived at the desired fluidity. Having acquired this knowledge in the first charge, the proper fluxing materials are afterwards added at once, as long as the same class of ore is to be worked.

The chemical metamorphoses going on within the furnace are few and simple—merely the formation of a silicate of iron, and the consequent evolution of sulphurous acid and sulphur, with a few other changes. It nearly always happens that sufficient silica is present in the ores, at least in those raised in England, to take up all the iron; but when this is not the case a proportionate quantity of quartz sand is added. Oxide of iron manifests a great affinity for silicic acid at a high temperature, and combines with it, under this circumstance, in preference to any other volatile acid; hence the iron present in the ore in the state of sulphide, or rather in the calcined ore in the state of either oxide or sulphide, is converted into silicate of iron. It is necessary, however, to bring the substances into a very intimate contact before this combination can be induced, and hence the reason for adding a fusible flux. Silicate of iron already formed and fluor spar are the best suited for the smelter, as they readily fuse and form a bath in which the combination of the iron and the silica is effected. A commotion is caused by the evolution of sulphurous acid which greatly favours the chemical action; and in cases where fluor spar is employed this is maintained after the sulphurous acid ceases to be evolved.

The manner in which the fluor spar, or calcium fluoride, acts, is by parting with its fluorine to the silica, which should be present in excess, thus giving rise to gaseous silicium fluoride, the lime being oxidized. The most important part of the decomposition, however, rests upon the union of the iron and the silica.

The matt or regulus is a brittle substance of uneven fracture and semi-metallic bronze lustre.

Third Process: Calcination of the Coarse Metal.—If the coarse metal has been run into moulds, the cakes are broken up and heated with free access of air in a melting furnace. The matt which has been granulated is taken from the tank, dried, weighed, and conveyed to the furnaces, where it is to undergo the third process. These furnaces resemble in size and outline those devoted to the calcination of the crude ore, and the charge of matt is, as in the former case, about 3½ tons. This quantity is thrown into the hopper surmounting the dome of the furnace, and let down into the bed in the usual way by drawing the slide, and afterwards spread out upon the sole in the same manner as was done with the crude ore. The same purpose is here intended as in calcining the crude ore, namely, the expulsion of the sulphur, and the production of oxidized bodies; but as the chief part of the gangue is removed in the preparation of the matt, these results will now be much more effectually produced than when all the impurities were present. Great attention must here be given to maintaining the heat of the fire within bounds, so as to keep the material at just such a state of ignition as will facilitate the expulsion of the sulphur, but will be insufficient to fuse the mass, which would prevent its oxidation in an effective manner. On the whole, the heat is much higher in this than in the first operation, more especially towards the end of the roasting, which occupies about twenty-four hours. For this purpose 21 cwts. of coal are required, or three and a half quarters of a cwt. per hour. During the first two hours the fire is kept low, and then as the sulphur becomes eliminated it is increased regularly, so that in the course of about twelve hours the ore has attained an incipient red heat. At the end of eighteen hours the whole of the interior of the furnace should be at a cherry-red heat; and at the close of the operation the temperature of the whole should have assumed a bright redness. Every two hours the action of the fire is accelerated by a rabbling of the charge, by which a fresh surface is exposed to the flame, and the sulphur compounds become decomposed. Much importance is attached to the proper calcination of the matt in this operation, and, therefore, it is not left to the discretion of the furnace-men; inspectors are appointed to attend each set of furnaces, and see that the work is duly attended to in every particular, especially the rabbling, which takes place at an interval of every two hours. If this be neglected, the whole of the sulphur will not be expelled in the form of sulphurous and sulphuric acids. Too high a temperature is less to be feared than too low a one, because the tendency of the ore to form masses will check the furnace-man's inattention in this respect, as he would have to break them up afterwards—a very laborious operation. When too little heat is applied, there is little danger of the charge agglutinating, and the rabbling is easily performed; but this is at the risk of not expelling the sulphur.

The change produced by the third roasting is expressed in the annexed table, which shows the relative weight of materials taken:—

Coarse metal,	0·804
Oxygen derived from the atmosphere,	0·196
	1·000

The products obtained by calcination are:—

Calcined coarse metal for the succeeding operations,	0·783
Sulphurous acid and sulphuric acid,	0·217
	1·000

The physical appearance, as well as the chemical composition of the matt, has altered; it suffers a diminution in bulk, and assumes a black hue. Throughout, the mass is friable, but where the grains are large and more solid, the exterior parts are easily reduced to powder, and the interior nucleus is hard and compact. After the whole charge is properly calcined, it is raked out through openings immediately inside the working doors, and falls through into a chamber under the hearth. This is called *calcined coarse metal*, and is, as soon as convenient, submitted to the next process.

Fourth Process: Fusion of the Calcined Coarse Metal.—It must be first noted that to the above product of the third process are now added the slags from some of the later processes, and other materials that may be enumerated below, and all is now melted down together.

The procedure in this stage of the work is analogous to the fusion for *matt* in the second process. It has for its object the removal of the iron, and the production of pure sulphide of copper, or at least as rich a compound as possible. The furnace used is of the same form as the melting furnace of the second process, except that there is no hollow in the hearth, but a gentle slope towards that side in which is the tap-hole by which the fused material is run out.

The material acted upon may consist of *granulated coarse metal* (to the extent of something more than one-half of the whole charge), *roaster slag* from the fifth process, *refining slag* from the sixth process, fresh ore of the fourth class, that is, rich ores with more oxide than sulphide, and without iron, besides copper scale and furnace waste.

Although the work in this process is simple, yet it is more difficult of management than any other yet described. The chief point to be attained is the blending of the calcined matt and the crude ore already mentioned, in such a way that the oxide of copper in the whole may be converted into sulphide by the impurities or sulphide of iron in the latter. It becomes a difficult matter to apportion the different materials. The whole charge being from 2 to 2½ tons, the percentage, on an average, may be represented as follows:—

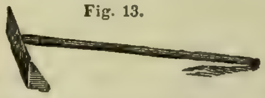
Calcined coarse metal,	56
Crude ores,	24
Slags from later operations,	10
Copper-scale, furnace-waste, and earthy matter,	10
	100

But these proportions should be made to vary according to the character of the ore and the slags. The only criterion which workmen have for their guidance is deduced from their observation on the first charge of a batch of these products. Practically the best decomposition is obtained, taking all allowances for the inequality of the oxygen and sulphur compounds into consideration, when the fusion is prolonged; and it has also been found that a better yield in quality, as well as in quantity, is ultimately produced when from 4 to 8 per cent. of iron are retained in the matt, and from 3 to 5 per cent. of copper pass off in the slag. This slag forms a very important article in the operations of the smelting house, as it contains a very large quantity of oxide of iron, having generally about 50 per cent. of protoxide of iron, and about 3 per cent. of oxide of copper, combined with silica, which, when added to the calcined ores in the first fusion, forms a most excellent flux for the ore, which otherwise would require extra calcining, or addition of a flux of lime or fluor spar, which would add much to the cost of the operation. The enriching of the slags with oxide of copper is not an inconvenience in the work; nor is any loss suffered in consequence, but a saving, as all the slags produced in this, as in other processes, are fused in the second operation, and the copper in them recovered in the matt, which it improves and enriches. Should, however, too much oxide of copper be permitted to remain in the slag, it would react upon the sulphide of copper, and reduce a portion of it to the metallic state. When this happens, the metal is usually of a bad quality. Indeed, it is the chief aim of the furnace-man to prevent this; dividing his attention, however, with the production of the purest white metal that is possible under the circumstances.

The materials, in the proportion indicated in the table already given, or in such quantities as the judgment of the furnace-man suggests, are introduced through the hopper, and spread out in the usual manner; the larger portions, especially the scoriæ, are thrown in at the working door, and distributed evenly over the surface of the charge.

When this is done, the doors are closed, and then luted, and the fire regulated to enable it to give out the required heat. At the expiration of an hour incipient symptoms of fusion appear, as well in the softening of the mass as in the evolution of the gaseous matter; the fusion of the whole progresses gradually till about three hours after charging, when it appears in two layers, the one as yet undissolved, floating on the fluid portion. All the volatile bodies evolved during the fusion rise from the double decomposition which takes place in the melted matter, but at the above period these are not disengaged in such abundance as to generate an effervescence in the mass. In about four hours after the charging the matters adhering to the sides of the furnace are struck into the bath, and the whole rabbled with an iron tool of the form shown in Fig. 13. At this period the flux, or scoria, is very fluid, and in a very short time, when the heat is increased, the whole mass is in tranquil fusion. The entire operation is completed in about six hours after the charge has been introduced. The furnace-door is then opened, and the attendant, by means of a long rake, skims off the scoriæ or slag; generally the bed for the slag has partitions, by which it is formed into pigs, or ingots, and these are removed and examined with greater facility than when in one mass. The tap-hole being now carefully opened, the very fluid matt, which at this stage has nearly attained to a white heat, flows out either into the cistern to be granulated, or it is conducted into channels in sand, where it is cast into pigs of about 1 cwt. each.

Fig. 13.



This is either *blue metal* or *white metal*, according to the amount of decomposition that has gone on. "White metal" contains about 75 per cent. of copper; it is an almost pure sulphide of the metal (Cu_2S), and is free from metallic copper. "Blue metal" contains about 56 per cent. of copper, 16 of iron, a large proportion of sulphur, and is usually vesicular with threads of copper projecting into the cavities. The slag is the *metal slag* treated in the second process.

Fifth Process: Roasting the Blue or White Metal.—The above regulus is now melted *with access of air*. This is done in a furnace like that wherein the former melting processes were effected, but having a side and an end door, and side openings for the admission of air. From 3 to 3½ tons of the regulus are introduced in large masses by the side door, and piled upon the floor of the furnace. The fusion is effected in about six hours; at this stage slag is skimmed off; then the heat is continued for several hours, during which time oxidation of the sulphur combined with the copper takes place, the melted material being as it were in a simmering condition from the escape of sulphurous acid gas. After a time the temperature is allowed to become so much lower that the surface begins to solidify; again the temperature is raised, and more oxidation goes on, till, after about twenty-four hours, it is thought that the process has gone sufficiently far, when the tap-hole is opened, by which the metal flows out into rectangular moulds formed in the floor of the foundry. This is called *blister copper*, on account of its numerous bubbles. The scoria (which was first skimmed off at a comparatively early stage, and lastly run into moulds just before tapping) bears the name of *roaster slag;* it is composed of silica, combined with the oxide of iron (FeO?) and some oxide of copper (Cu_2O?) from the regulus, and about 2 per cent. of sulphur; it is this that is added to the charge in the *fourth process.* The composition of blister copper is very constant, averaging from 93 to 96 per cent. of copper, with a little sulphur and oxygen, the latter being in all probability combined with the copper in the form of suboxide, which compound was *dissolved* by the metallic copper. The following may be considered a fair specimen of good blistered copper:—

Copper,	95·60
Sulphur,	·69
Iron,	·28
Silica,	·12
Antimony,	trace.
Oxygen and loss,	3·31
	100·00

The reaction taking place in the above process is explained by Dr. Percy as a formation of oxide of copper on the first slow melting of the mass, then, as it fell, an interchange with undecomposed sulphide, by which sulphurous acid and metallic copper resulted.

The advantage of checking the heat and afterwards raising it consists in this, that on the partial cooling the surface bursts out into volcano-like protuberances that afford a larger surface for further oxidation; the last raising of the temperature then mixes the later formed oxide, and causes a further reaction of the kind above described, so that nearly all the sulphur becomes expelled, the oxidation being at the same time so far carried to excess that some of the copper is oxidized, and qualities are produced in the metal which have to be corrected by the next process.

Blister copper contains about 95 per cent. of copper, together with small quantities of iron, sulphur, tin, antimony, &c. It is brittle, and has a deep red colour. It cannot be used in the arts on account of its want of tenacity.

Sixth Process: Refining the Blister Copper.—In this the toughening and refining of the copper, so as to bring it to a fit state for the market, are performed by a method similar in some respects to the preceding operation.

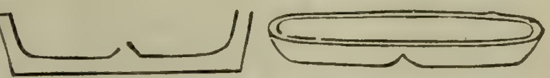
A charge of the pigs of blistered copper, weighing from 8 to 10 tons, is introduced by means of a peel into a furnace of the same construction as that used in the last operation, except that the grate is larger on account of the increased consumption of fuel required to maintain the proper heat, and that the hollow of the bed is towards the far end. Siemens' regenerative furnace is much used. The only additions to the metal till the preliminary roasting is completed are the adhering sand and part of the matt of the furnace; these are subsequently thrown off as scoriæ. Care is taken in the introduction of the masses of metal to place them so that the greatest amount of surface shall be presented to the flame, and likewise that the draught may not be impeded. This being done the fire is attended to, and the heat sustained during the eighteen hours that the charge is left to roast. This is so managed that, in about six hours after the charging, the copper begins to melt freely, and the heat continuing to increase regularly, brings the whole, within the period of eighteen hours, to such a state that the oxides of any foreign bodies, together with some oxide of copper, will unite with the silica. What remains of the iron, or any other metal, in the molten bath, unoxidized by the current of air passing through the furnace, is oxidized by means of the oxide of copper, which is thus decomposed into metal and oxygen. The high temperature is maintained during a further period of three and a half or four hours, which renders the bath of metal as free from impurities as is possible under the circumstances. The working door is now opened, and the bath is found covered with a layer of scoria which is raked off, leaving the metal in the state that is called *dry*, that is to say, brittle, from the presence of diffused suboxide of copper (cuprous oxide, Cu_2O).

The second part of the process now commences. Hitherto one man had the care of two furnaces, but now more men are employed, and the preceding part of the business is so regulated that each furnace will be ready at the usual working hour in the morning. At this stage the metal is brittle, of a deep red colour, and coarse fracture; tenacity is to be acquired, as well by removing the oxygen as by causing a different aggregation of the molecules of the metal. The first thing which the refiner has to learn is the state of the *dry* copper, as it is called, and this is done by taking out a sample with a small ladle and casting it in a mould; when cold this is broken, and from its appearance, together with the state of fusion and the intensity of the fire, he calculates the quantity of charcoal, wood, or of coal, which will be requisite to communicate the suitable degree of toughness.

Ground charcoal, or the best anthracite coal, is scattered over the surface of the metal, and serves both to exclude the air and to deoxidize those portions of the metal in contact with it.

This constitutes the first step, but the action of the carbonaceous covering thus used cannot penetrate beyond the surface, and hence the oxygen in the interior remains unacted upon by it. To expel this it has been the practice, time out of mind, to agitate the fluid metal with a spar or pole of green wood, either birch or oak, and this continues at the present time to be the only method in use. One of these poles is thrust into the fluid bath, and the carbonaceous gases which it evolves effectually reduce, during their ascent through the fluid metal, any oxide of copper, carbonic acid being evolved. The two gases throw the metal into violent commotion, which serves to bring every particle of the red oxide of copper within the range of the deoxidizing agents. The ebullition of the metal by the action of the poles is continued from fifteen to about twenty-five minutes or half an hour, the surface being still kept covered by fresh additions of charcoal or coal. The period for arresting the poling is ascertained by taking samples from time to time, and testing their ductility and malleability in the vice and under the hammer. For this purpose the refiner has a small ingot mould attached to the end of an iron rod, and this he quickly dips into a spot at some distance within the door, from which he has cleared away the coal and scoria. When the sample solidifies, it is cut half through by a chisel or shears, and then repeatedly bent by blows from a hammer whilst it is held in the vice. By various trials, made in this way, of ingots taken from the charge, some of which are broken when cold, hammered on the anvil while red, or cut, the knowledge of the point when no more oxide of copper remains, and the grain of the metal becomes sufficiently fine, is arrived at with considerable precision. Long and diligent observations are required to be able to detect this point with certainty, because the several assays vary to some extent in every variety of copper according to their malleability; and so with the repeated samples taken from any particular species from the first to the last during the refining. When the poling has not been continued long enough, the ingot, when cut and broken, appears almost devoid of metallic lustre, and has a brick red colour, and a fracture which is dull and granular. Upon continuing the action of the charcoal and the birch spars, each succeeding ingot shows an improvement in the grain, and also in the colour of the metal, in proportion as the required point is neared, till finally it assumes a beautiful silky lustre, and a fine pale red hue. When these characteristics appear, the refining is considered to be finished, and the assayer directs the workmen to withdraw the spar of wood, and prepare for casting. The fire which, from the commencement of the poling, was cut off from the metal by conducting the draught through another flue in the upper part is now redirected on it; and after the coating of scoria, which resulted from the ebullition of the metal and the combustion of the fuel, has been raked off, and a few shovelsful of charcoal thrown upon its surface, the superior flue is closed, and the heat carried through the furnace as usual. In this way the metal is retained fluid, and the layer of charcoal takes up any oxygen which may pass over it, so that there is no possibility of further oxidation. The men now proceed to cast the copper into moulds of suitable dimensions—such as are represented in Fig. 14—using for the purpose ladles which have been coated with clay.

Fig. 14.



The utmost caution and expertness are required on the part of the refiner, in order to judge of the relative purity of each sample as he draws it out, and which varies with every variety of metal; for if the poling be prolonged only a few minutes beyond the time at which the assay shows, from its silky grain and fine rose colour, that the refining is completed, it would deteriorate the product considerably. Under such a condition the grain becomes coarser, and the lustre, though still retained, loses the silky appearance of the well-refined metal. Should the poling be still further continued, it will render the grain of the metal rougher, the fracture fibrous and striated, and the brittleness will be increased even more than when it was in the *dry* state, in consequence of the formation of a carbide of copper. When such an occurrence happens the coating of charcoal is skimmed, and the bath exposed to the air passing in through the fire and rushing in at the doors, which has the effect of bringing it back to its ductile state once more. In like manner, if the metal is kept covered with charcoal during casting, injury will arise from the absorption of oxygen, and the refining will, in the language of the operator, go back. When this is the case, recourse must be again had to the spars of wood to reduce any oxide that may have formed.

Sometimes considerable difficulty is experienced in bringing the copper to that state of purity necessary to insure its sale; and when other metals are present, the gas liberated from the spars of wood fails to have a beneficial effect. In this case it is better to add some lead, and to rabble the bath thoroughly for some time: this metal, while divesting the copper of oxygen, forms a medium through which the iron, arsenic, tin, &c., are converted into oxides, and thrown off as scoria, on account of its great affinity for oxygen. Care must be taken, however, that the agitation is sufficient to bring every particle of the lead within the influence of the air at the surface of the molten mass, where it is converted into litharge and removed by the rake. Should any of it remain in the copper, it would occasion difficulty in lamination, by preventing the scales from falling cleanly off the surface. The results of the charge operated upon, and represented as follows:—

Coarse copper,	0·954
Earthy matters, sand,	0·013
" " brick and clay,	0·021
Oxygen of the air,	0·012
	1·000

are as follows:—

Saleable copper,	0·908
Slag for operation four,	0·055
Furnace waste do. do.	0·022
Copper sweepings do. do.	0·002
Sulphurous acid,	0·013
	1·000

Patented Improvements.—Although the result of all experiments has been to prove the above process (modified in details according to the character of the ore to be treated and the quality of metal desired) to be the best on the whole, yet it may be well to give an account of some of the various patents that have at different times been granted for improved methods, since, even when these have not been generally introduced, something is sure to be learnt from the experiments and attempts.

Brankart's Patent was especially intended for the reduction of rich South American and other foreign ores. The principle of the patent is the conversion of sulphide of copper into a sulphate, extracting this from the gangue with water, and precipitating the metal by iron, which is, during the operation, converted into sulphate or copperas. The ores suited to this treatment are copper pyrites and sulphides from the Cuban mines. These are known as *Cobre ores*, and generally contain from 15 to 25 per cent. of metal, together with iron and other impurities. The course which the patentee recommends is to reduce the substance to powder, and then expose it during several hours to the heat of a calcining furnace, by which considerable quantities of the sulphur are dissipated as sulphurous acid, whilst another portion is converted into sulphuric acid, which combines with the oxide of copper. When this process has been sufficiently prolonged, the ore is raked out and thrown at once into large vats filled with water. The sulphate of copper is dissolved, and after a short time the liquor is slowly allowed to flow out into another tank. The residue which remains on the bottom of the vat, and which still contains some metal, either as oxide or sulphide, is dried, and afterwards mixed with a proper quantity of the fresh ore and heated as before, when, by the reaction of the air the sulphides and sesquioxides of iron, the sulphur will be converted into sulphuric acid; this unites with the oxide of copper, and forms a sulphate which may be washed out in the manner already indicated. When the proportion of sesquioxide of iron increases in the exhausted ore no copper is lost, for it causes the formation of enough sulphuric acid from the sulphur in the crude mineral as will combine with the whole of the copper that may be present. Quantities of iron are thrown into the liquor, and the metal precipitates in the course of a few days, after which the supernatant liquor is decanted, the precipitate washed well with water, then dried and submitted to a slight process of refining. The sulphate of iron is obtained from the liquor by evaporation. (See Wet Processes.)

Rivot and Phillip's Patent.—This so far agrees in principle with Brankart's that it is founded on the greater affinity of iron than of copper for the impurities. But in this process it is the *oxygen* that is made to combine with the iron, oxygen which is left combined with the copper after the ore is roasted *dead*, that is, when all the sulphur has been expelled. Bars of iron are then introduced through apertures made for the purpose in the hearth. As soon as these come into contact with the heated material, which at this stage consists principally of oxides and silicious matters, reduction of the oxide of copper ensues owing to the greater affinity of the iron for oxygen, especially in the presence of sand. The oxide of iron which is thus formed is contained in the slag, which is subsequently skimmed from the metallic bath, united with silica. This operation is most suitable for rich ores; but if they contain other metals which affect the quality of copper, they cannot undergo smelting in this way, as the arsenic, tin, &c., would remain in part with it, and render it unfit for general use. Were it not for this, and the destruction of a large quantity of iron, the process might be brought into requisition, as by it very fair metal could be obtained at one operation.

Napier's Patent.—In smelting, the chief object is the separation of the silicious earthy impurities, the iron, and the sulphur usually associated with the copper; the quicker and more completely this is performed, the more profitable will be the method of working, for not only will saving in labour and fuel be effected, but the quality of the metal will be improved. In the method under consideration, it is directed that the ores from Cornwall and such as are similar to them, as well as those imported, be calcined in an ordinary furnace. This product is next mixed with a quantity of rich Cobre ores, or other sulphides having a high percentage of metal, the proportion being inferred from their analysis, as well as from the fact that the iron and silica combine to form a clean fusible slag, and that the resulting matt should contain from 30 to 50 per cent. of copper. The mixture is now to be introduced into a reverberatory, and fused as when preparing *coarse metal* or *matt*, and when the fire has thoroughly effected the liquefaction of the constituents the scoria is raked. At this stage a quantity of soda ash (crude carbonate of soda) or salt cake (sulphate of soda) is introduced and rabbled with the mass. The alkaline salt undergoes decomposition and becomes a sulphide, which dissolves any arsenic, tin, or antimony that may be present, and carries them off in combination when the mass is afterwards treated with water. If salt cake be taken, it is necessary to mix it with charcoal to reduce the sulphuric acid more effectually, and bring it to the state of sulphide; the quantity used being 20 to 30 lbs. to 1½ cwt. of the soda salt, and this mixture serves for 1 ton of the matt. A very short time suffices for the decomposition of the sulphate, so as to cause it to react upon the impurities already noted. When this decomposition is considered to be finished, the furnace is tapped, and the mass cast into moulds of a rectangular or other suitable shape. As soon as these solidify, so as to bear removal, they are put into tanks filled with water, where they disintegrate into an impalpable powder. After some time the water is siphoned, or otherwise allowed to flow off, and the sediment washed to remove the soda compound, and with it the arsenic, tin, or antimony which it dissolved, if they were present.

The finely-divided residue is next dried, and submitted to heat in a calcining furnace till the last traces of sulphur are eliminated; this, owing to the minute state of division of the matt, is done in twenty-four or, at most, thirty hours. Having thus reduced all the copper to the state of oxide, the latter is now to be mixed with a quantity of fresh mineral which is free from sulphur and arsenic, but rich in silica, and with coal or charcoal, and the compound treated in a smelting furnace in the ordinary way; reduction will take place, and a slag will be formed which will not retain much either of the metal or of its oxide.

BIRKMYRE is another of those who have experimented on copper reduction. He burns the copper pyrites so as to recover all the sulphur in the state of oil of vitriol and sulphates of iron and soda. The mineral is finely ground, then placed upon trays, which are sufficiently capacious to hold about 1½ cwt., and these are introduced into kilns similar to those in common use for burning pyrites.

Before submitting the ore to the heat of the kilns, it is mixed with a quantity of nitrate of soda, in order that the sulphur may be converted into sulphuric acid during the combustion. After an hour's calcination the trays may be withdrawn and their contents cast into water, where the sulphates of copper and soda produced during the foregoing part of the operation are washed out, leaving the gangue in the bottom of the tank.

The copper in this, as in NAPIER'S process, is entirely freed from arsenic, which is expelled in the form of arsenious acid during the roasting. The metal is recovered from the saline solution by precipitating it with iron.

CHARLES LOW proposed to simplify the labour of smelting by employing a combination of binoxide of manganese, plumbago, nitrates of potash, soda, or lime, and charcoal, as a flux. The proportion in which these are blended with each other is as follows:—

42	parts of	binoxide of manganese.
8	"	plumbago.
2	"	nitrate of potassa, soda, or lime.
14	"	wood charcoal or anthracite.

While the fusion for matt is going on, a quantity of this flux is added and mixed intimately by rabbling, in order to cause the separation of the silicious and metallic impurities as scoria, and also to render this more fluid than it is on ordinary occasions, that it may be less able to retain any of the matt or metal. Twenty-five pounds are first used; and when the fluid slag rises to the surface it is skimmed, and the above weight of the flux again rabbled with the molten mass, and the scoria which it produces separated as before, and so on till the workman judges that the metal has arrived at a sufficiently forward state for it to be run off.

Trueman and Cameron's Patent recommends the following course:—When sulphide of copper, or substances containing sulphur, are to be operated upon, the patentees roast them in the ordinary way to procure a matt of coarse metal, which is afterwards ground, and a portion submitted to analysis, to ascertain whether tin, arsenic, or antimony is present. If these be detected, the powdered matt is boiled with a solution of caustic potassa for six hours, keeping the contents of the vessel well stirred during that time. The object of this is to remove those metals in the form of salts, namely, as potassium, stannate, arsenite, and antimonite. After the solution is drawn off, the residuary matter is calcined to remove all, or as much as possible, of the sulphur, and produce an oxide, which is subsequently mixed with sulphide of copper in such a proportion that the oxygen in the oxide will be sufficient to form sulphurous acid with the sulphur in the crude ore. It is likewise necessary that the silica in the mixture should correspond with the iron, so as to yield a fusible slag; if, however, there is not enough silica present to take up all the iron, then a certain weight of sand, or preferably, the bottoms of old furnaces, called *cobbing*, must be mixed with it. The components of a charge which affords the metal with facility are thus stated, namely:—

26 parts of calcined powder, having 47 per cent. of oxide of copper.

12 parts of Cobre ores, containing centesimally,	copper,	26
	iron,	26
	silica	16
	sulphur,	32
12 parts of cobbing,	silica,	72
	copper,	12
	iron,	6

About 2½ tons of this mixture are submitted to the furnace and fused; five hours after the charging the whole is rabbled, then allowed to rest, and the slags skimmed as they rise to the surface; the fluid matt is not drawn off as usual, but another charge is introduced and worked like the preceding, after which the furnace is tapped. A rich compound of copper and sulphur, free from iron or nearly so, is separated, and when calcined and fused in furnace it yields metal of good quality.

Foreign Modes of Copper-smelting.—The modes of smelting copper pyrites, and other sulphurous ores of copper described above, are those adopted in England and Wales. On the Continent, however, the minerals differ from those found in Great Britain, and a different mode of smelting is adopted.

Many ores are found besides the sulphides of copper; such are the oxides and suboxide known as *black* and *red* ore and the *azure* ore or carbonate. These require a special mode of working distinct from the routine described, while, as will be seen below, the quite other circumstances of the *Mansfeld* ore necessitates yet other treatment. A description of two or three of these continental methods will now be given.

Copper-smelting at Chessy, in France.—The ores of Chessy, near Lyons, in France, are the azure and red variety, the former not discovered there till 1812, and the latter in 1825.

The annexed analyses of the rich and poor class of *red* ore of this locality shows that their smelting is not a very difficult procedure:—

	Centesimally represented.	
	Rich.	Poor.
Suboxide of copper,	86	45
Sesquioxide of iron,	4	20
Aluminous and silicious matters,	5	30
Water,	4	5
Loss,	1	0
	100	100

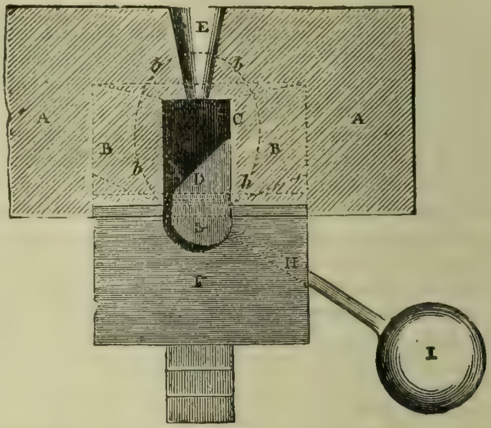
The composition of the *blue* ores likewise shows that they are capable of yielding a good return, and can be worked with comparative facility:—

	Centesimally represented.			
	Rich ore after picking and washing.	Rich ore after sifting.	Poor ore after washing.	Poor ore after sifting.
Protoxide of copper,	45	42	30	25
Oxide of iron,	1	4	2	5
Aluminous and silicious matters,	30	30	52	55
Carbonic acid and water,	23	22	15	14
Loss,	1	2	1	1
	100	100	100	100

These minerals are smelted at once in a furnace, called by the French *fourneau à manche*, shown in the annexed Figs. 15 and 16.

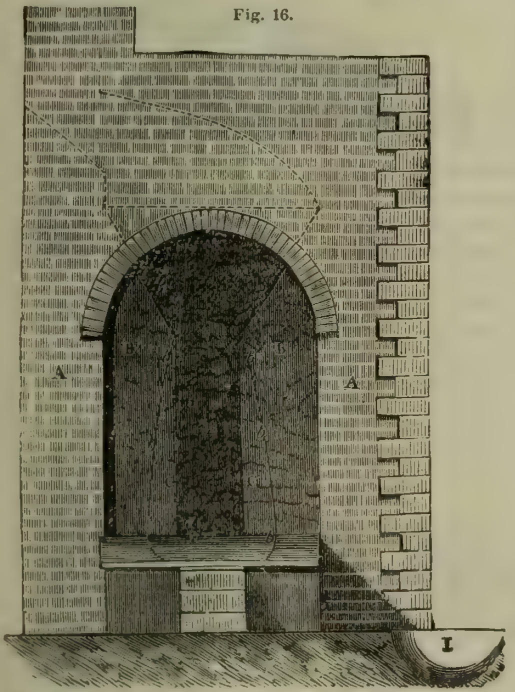
The first of these is a horizontal section on a level with the tuyere, or pipe which directs the blast, and the second an elevation. The base of the furnace, A A, is constructed of solid masonry, strengthened by transverse bars of iron. B B is a coating of refractory material, which is renewed every season; it is cemented to the masonry in the form of an ellipse, as shown in the dotted line. The two lateral faces are formed of gneiss, and the front one, called *fiervende*, is constructed of rectangular iron plates, coated with fire-clay; these are supposed to be taken off in the figure. C C shows the form of the coating at the time of the firing; it is a rectangular parallelopiped of about 6 feet in length, 5¼ in breadth, and about 3¼ feet in depth. D is the sole, composed of firebrick made from Bourgogne clay and pulverized quartz. E is the tuyere; its orifice is 3 inches in diameter. F is the platform or table, constructed of clay firmly beaten between the fore part of the furnace and three small walls which are bound by iron bars. Three steps are made in front for the convenience of the ascent of the workmen. G is a basin or crucible dug in the table in the front of the fire; it is made on a level with the sole of the furnace. It is coated with a mixture of clay and powdered charcoal, which preserves it from injury for weeks together. H is an inclined canal opening into the recipient, I, where the fluid collects.

Fig. 15.



The ore to be smelted in this furnace is mixed so that the mean content of metal will be about 27 per cent.; to this 5 per cent. of caustic lime are added, together with a small amount of scoria. 200 lbs. of this mixture, mingled with about 250 lbs. of coke, are introduced into the furnace hourly when the latter is in good working order. As the fusion and reduction proceed, the melted metal and scoria flow out into the bath opposite the fire, from which the latter may be separated by skimming it off. In about twelve hours the basin opposite the fire is filled with metal, which may be run off in the ordinary way into the recipient, I. Any scoria which may be carried over floats on the surface, and can be easily removed. A little water is next sprinkled upon the metal; its evaporation causes the formation of a solid crust, which is taken out of the bath by a circular implement. By continuing this operation the whole contents may be converted into cakes or discs of three quarters to one inch in thickness. The running takes place twice each day, and on the whole there is about 13¾ cwts. of metal. It is necessary to repair the basin opposite the fire once a week. The products of the foregoing fusion are the ordinary slags formed in the furnace and those produced in the recipient, the black copper and other matter being carried off in the flue. The scoria is of three kinds, the blue, the black, and the red, but some of these retain only very small quantities of copper, as seen in the annexed table :—

Fig. 16.



	Blue Scoria. Per cent.	Black Scoria. Per cent.	Red Scoria. Per cent.
Silica,.............	55·0	56·0	58·6
Alumina,..........	7·0	9·0	5·0
Lime..............	24·6	27·0	16·0
Protoxide of iron,...	11·9	7·0	12·6
Protoxide of copper,	0·5	0·7	0·0
Suboxide of copper,.	0·0	0·0	6·6
Loss,..............	1·0	0·3	1·2
	100·0	100·0	100·0

The blue slags contain very little oxide of copper; they are formed when lime is present in sufficient quantity. Black slags are produced when the above earth is wanting, and the iron of the ore vitrifies the silicic acid of the mixture; they have more copper than the blue variety, and are often coated with a red scoria, which is indicative of the combination of oxide of copper with silica. Red scoria is composed of silicate of iron and copper, and is evidently the result of not having the sand, quartz, &c., proportioned to such bases as would take it up and wholly prevent its union with the copper; this, however, is not the only cause, for the same result follows the application of a high temperature in the furnace. The formation of these slags rich in copper is a sure sign that the heat of the furnace is too elevated, which causes them to run so quickly that the copper cannot be sufficiently reduced.

It may be conceived, likewise, upon similar grounds, that minerals which are very rich are more difficultly treated than when they afford a large amount of slag; because the time necessary to effect the fusion in the latter instance is sufficient to reduce the metal completely, and hence, when the fused mass runs out into the crucible, scarcely any red slag is found in it. A proper amount of fluxing material always keeps the scoria free from copper, and any derangement in the working may be readily rectified by altering the mixtures operated upon, or diminishing the blast.

The composition of the scoria thrown off from the metal, after it flows over to the recipient, is—

	Centesimally.
Silica,................................	30·5
Protoxide of iron,......................	55·5
Sulphur,..........	2·3
Iron, ...	1·8
Copper, ...	4·4
Sand, ...	0·5
Loss,...................................	5·0
	100·0

This slag differs from the foregoing in not containing lime. The action of the air upon the bath of metal oxidizes a large quantity of the iron as well as some copper, and these reacting upon the silicious coating of the crucible, occasion its formation.

The black copper which results from these operations is of very variable composition. When the scoria is black the metal is found charged with iron to the extent of 7 or 8 per cent. Even in the same running much difference may be observed in this respect, for the copper being denser than the metals accompanying it, settles to the bottom in large quantities, and hence the last cakes are richer than the first. The annexed is the mean of several analyses by M. Margerin of black copper thus obtained:—

	Per cent.
Copper,................................	89·30
Iron,..................................	6·50
Protoxide of iron,.....................	2·40
Silica,................................	1·30
Sulphur,...............................	0·34
Loss,..................................	0·16
	100·00

The above kinds of ore might be worked with advantage in a reverberatory furnace heated with coal, mixing therewith some powdered charcoal, sufficient lime, and a little scoria to facilitate the fusion. The copper would thus be obtained entirely or nearly free from iron and sulphur.

For many years past an ore called *black mine* has also been obtained from Chessy, which is composed, according to Thibaud and Berthier, of—

	Per cent. Rich mineral.			Per cent. Another sample.
Protoxide of copper,	12·00	14·0		22·67
Copper pyrites,....	56·35	46·1		20·15
Iron pyrites, ...	25·01	36·3		8·94
Sulphate of barium,	2·60	0·0		28·80
Sesquioxide of iron,	0·00	3·0		9·22
Loss,............	4·04	0·6	Sand, &c.,	20·22
	100·00	100·0		100·00

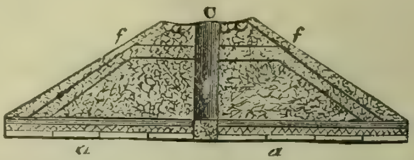
It is smelted in a furnace similar to that last described, without any previous preparation, except that half of the scoria from a foregoing charge, together with half from the smelting of carbonated ores, which are rich in lime and alumina, is added, to render it more fusible. In this way a matt is obtained which is afterwards submitted to five or six calcinations, in the same manner as that followed at Swansea and other places; and the decomposition of the sulphur compounds by the oxides is effected here in the way already explained. The sulphate of barium is decomposed by the coal used into sulphide of barium, which, reacting upon the oxide of iron, gives rise to sulphide of iron and baryta, which combines with the silica, and passes off in the scoria. An excess of heavy spar, however, is not desirable, as it occasions the presence of too large a quantity of sulphide of iron in the matt, which must be expelled afterwards at the cost of time and labour.

Copper-smelting at Mansfeld in Germany.—At Mansfeld in Prussia there is a cupreous schist, or rather shale, which, though yielding but a small percentage of the metal, is successfully smelted. This *kupferschiefer*, as it is called, which belongs to the Permian formation, is a bed of somewhat bituminous shale, a foot or two thick, of which, however, only a portion a few inches thick has enough of copper to justify its metallurgical treatment. This portion contains about 2½ per cent. of copper in the form of various sulphides, as well as other copper minerals. Of silver, also, there is a noteworthy amount, and there are small quantities of other metals.

The *first operation* is the roasting of the ore in mounds; in this the burning, which is begun by lighting some piles of brushwood laid beneath, is continued by the combustion both of the bituminous matter and the sulphur contained in the schist; not all the sulphur, however, should be eliminated. The mounds continue burning, according to the state of the weather and the size of each, for from two to four months. During the operation the ore loses about one-tenth of its weight, becomes friable, and acquires a yellowish-grey colour.

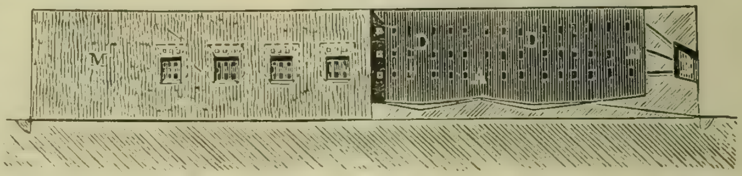
On the Lower Hartz, where there is an iron pyrites containing about 5½ per cent. of metallic copper, together with more or less antimony and arsenic, the method of procedure is such that some of the sulphur is recovered during the preliminary calcination to which the ore is submitted. The manner in which this is performed is shown in Fig. 17, which represents a vertical section of a mound in the state of calcination. The form is that of a truncated quadrangular pyramid, the base of which is composed of

Fig. 17.



wooden billets, *a a*, laid in such a way as to allow an access to the central wooden chimney, c. At the base of the latter some charcoal is kindled, and the heat penetrating the pyritous mass, *d d*, suffices to effect a decomposition by which a portion of the sulphur is expelled as sulphurous acid, and another quantity as free sulphur, which is condensed in the upper part of the mound. It requires careful attention for two or three days, in order that the fire may take hold; when this is done the mound is coated exteriorly with matt and refuse mineral, as shown at *f f*, so as to direct the draught to the top. By the

Fig. 18.



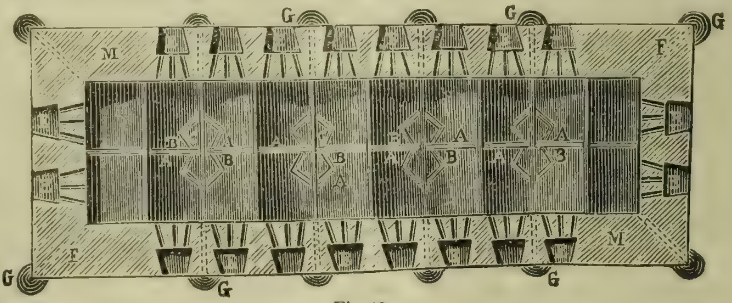
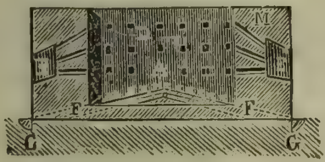


Fig. 19.

combustion of the wood on which the mineral rests the latter is ignited, and the heat developed by the converson of one portion of the sulphur into sulphuric acid is sufficient to maintain the whole in a state of ignition. A number of cavities are made in the top of the mound, into which, as the upper portion becomes surcharged with sulphur, it collects in a fluid state, and is thence removed by an iron ladle, and cast into water to be further purified. After the first calcination the mound is turned over, and such parts as had agglomerated are subjected to a repetition of the preceding process.

At Agordo the roasting is effected by the kiln shown in the accompanying figures. Fig. 18 depicts the kiln partly in elevation, partly in section. Fig. 19 is a horizontal section along the line of the doors. Fig. 20 is a vertical section across the furnace. Thick walls, M, surround the chamber, A, which is divided into sections. The bed of each section is a low pyramid, A A, having its apex at the centre of the furnace. Channels, B, are cut along the lines of junction of the bed plates, and also on the faces of the pyramid at C. Nine other channels communicate through the walls, M, with each of the chambers, which serve to collect the sulphur. The canals, F, conduct the liquid sulphur into the globular receptacles, G. The kiln is charged by building chimneys of lumps of ore upon the top of the pyramids, and after covering the gutters with flat stones, filling in the whole space between the chimneys and the walls with alternate layers of coarse and fine ore, with occasional layers of wood, to facilitate ignition. The roasting is complete in from five to six months.

Fig. 20.



The calcining completed, the Mansfeld mineral, in readiness for the *second operation*, is mixed with such ingredients as will promote its fusion. This mixture consists of relative weights of the schist, according to its composition, which is very variable, fluor spar, scoria rich in copper, and other refuse. Thus—

20 cwts. of ferruginous slate,
14 " calcareous slate,
6 " argillaceous slate,
3 " fluor spar,
3 " rich slags,

constitute an ordinary charge for the blast furnace in which the operation is performed.

Fig. 21 represents an elevation, Fig. 22 a vertical section, and Fig. 23 the base of the furnace used on this occasion; the last showing the outlets into the crucibles which receive the matt which results. In these figures A represents the shaft, B the rest, C the tuyere, D the apertures through which the fluid flows by the channels, E E, into the basins, F F—Fig. 23. The shaft is constructed of firebrick, lined at the back with some refractory and non-conducting material, generally rubbish stones, and the parts adjoining the *tuyeres* of pudding-stone, through which the heat passes very slowly. The hearth-stone, G, is inclined to the openings, D, to facilitate the effusion of the matt into the basins. Generally, the height of this furnace is from 15 to 18 feet; the breadth at the tuyeres, which are 2 feet from the sole, about 26 inches, and at the widest part 3¼ feet; the whole is surmounted by a chimney of 40 or 50 feet high, which conducts the gases out of the reach of the workmen.

The charge above described is introduced in portions alternating with the fuel, which is coke, and by the aid of the blast is melted in about fifteen hours. During the melting, the outlets, D, are opened alternately as each basin is filled with the molten mass, which flows out to one or the other continuously. From these receptacles the matt is removed in the form of circular plates, which are lifted off when sufficiently cool from the surface of the still liquid sulphides remaining in the bottom of the cavity.

Fig. 21.

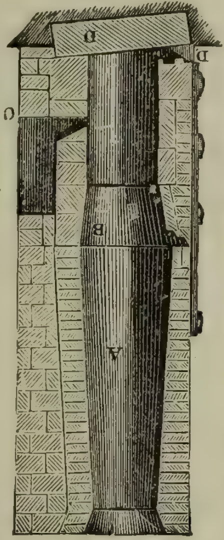
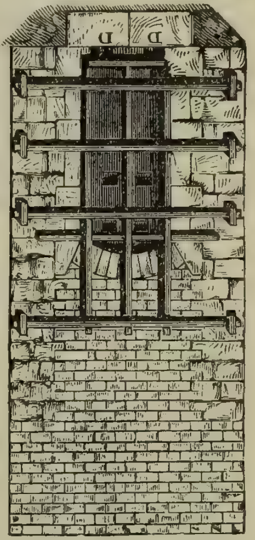
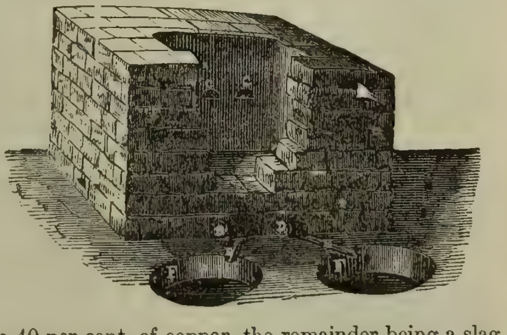


Fig. 22.



The yield is about one-tenth of the weight in a regulus, which is called *rohstein*, containing from 30 to 40 per cent. of copper, the remainder being a slag called *rohschlacke*. This *rohstein* corresponds to the *coarse metal* of the English process. New furnaces of greater size have latterly been erected; these have six tuyeres for a blast heated to 280° C., and they are made so that the waste gases are collected and utilized; otherwise the process with them is the same as in the older sort of furnace.

Fig. 23.



The *third operation* is the roasting of the *coarse metal;* this is done either in kilns or stalls, of which three sides are of strongly-built walls, the fourth of movable stones; some brushwood is required to start the combustion, and then the sulphur itself of the regulus burns. One roasting (though lasting ten or twelve days) is not enough for all the material; some of it has to undergo the same thing two or three times.

In the *fourth operation* the product of the last is fused with the addition of the richest slag from the previous melting, as a flux. Formerly the furnace employed for this was a cupola, but now a reverberatory furnace, on the plan of the melting furnaces of the English method, is used. The result is a regulus containing over 60 per cent. of copper and a proportion of silver. It goes by the name of *spurstein*, and may be called by us *fine metal.*

For some of the remaining processes of the system as at present carried out we follow J. A. PHILIPS. The *fifth process* is a grinding of the *spurstein*, which had previously been granulated; it is here ground fine in a mill and sifted.

The *sixth process* is an almost complete roasting; it is effected in a reverberatory furnace, the result being the conversion of the copper sulphide into oxide, and of the silver (which has before been mentioned as occurring in the ore) to the state of sulphate.

The *seventh process* has for its object the separation of the silver; it is a lixiviation of the last roasted product. The sulphate of silver is dissolved, the solution being run into other vessels; then from this solution silver is obtained by means of metallic copper, which precipitates it.

The *eighth process* is a melting of the residue of the lixiviation; it is done in a blast furnace similar to that used for the second operation; the oxidised product is mixed with flux and with coke for its reduction. The reduced metal (called *black copper*) contains 98·8 per cent. of copper; there also results a proportion of regulus of sulphide of copper, which is treated over again, and a slag, most of which is thrown away.

Fig. 24.

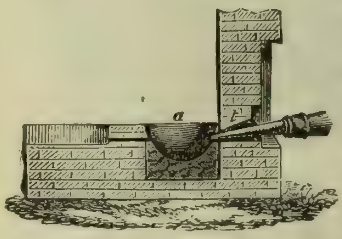
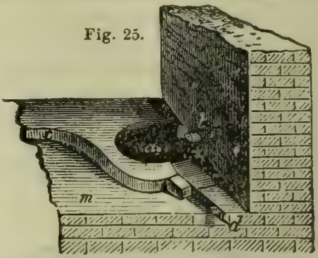
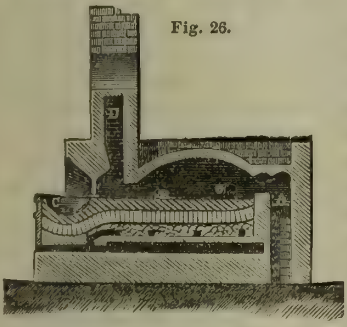


Fig. 25.



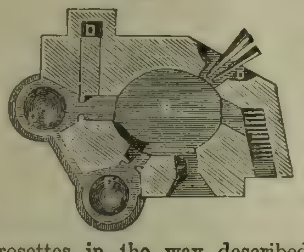
The *ninth operation*, and the last, is the refining of the black copper. It is done in two different ways. Figs. 24 and 25 exhibit the kind of hearth employed in one of these two. *a* is a hemispherical crucible 16 inches in diameter, and rendered fireproof by a luting composed of two parts of powdered charcoal and one of fireclay; *c* is an iron curb for keeping the fuel from being scattered about during the melting; *b* is the masonry, and *t* the tuyere of the hearth. The mode of charging is to fill the crucible with charcoal in an ignited state to desiccate it, if required. When this is done, more fuel is introduced, together with pieces of black copper, which are deposited opposite the tuyere. The blast is admitted by degrees, and as soon as the metal of the first charge has been fused, a further quantity is put in, with as much charcoal as will effect the reduction, and the work is continued till the crucible becomes nearly full of metal. The scoria, as it is produced, flows off through an opening, *d*—Fig. 25—into the receiver, leaving the metal at the bottom. After the whole of the black copper requisite to form a charge has been operated upon, the attendant begins to examine the product in the usual way, by taking samples out of the bath with an iron rod, and immersing them in cold water. When the assay appears brownish-red on the outside, and of a coppery lustre interiorly, together with exhibiting much brittleness, the refining is said to be finished. The blast is now cut off, and the cinders and slag skimmed with the rake; some cold water is next sprinkled upon the surface of the mass, and as soon as a solid crust is formed, it is removed and cast into cold water to prevent oxidation; more water is again thrown upon the metal, when another cake is formed, which is deposited in the tank in a similar way, and so on till the whole is converted into rosettes. 2¼ to 2½ cwts. form the charge for the furnace of the ordinary size; but sometimes as much as 7 cwts. may be operated upon in one of these hearths. For the first, three quarters of an hour are occupied in the refining, and about 1½ cwt. of metal in rosettes are obtained; but in the larger kinds of furnaces two hours are required. This product usually contains from 1 to 2 per cent. of other metals, such as lead, silver, iron, and aluminium. The first slag which is thrown off in this process has a greenish colour, and retains a large quantity of oxide of iron, but little copper; the next scoria, however, has a deep red appearance, and retains a considerable amount of suboxide of the metal, and, therefore, is subjected to further operations in the preparation of the black copper. *Rosettes*, as thus prepared, are never sufficiently refined to allow the copper to be rolled out into sheets, or manufactured into the ordinary articles; consequently it has to undergo a further treatment. The plates are melted in the hearth above described, the surface of the bath being covered with charcoal, in order to deprive the metal of oxygen. Samples are taken from time to time, and examined with great precision, and as soon as the true grain is attained the metal is cast into ingots. Sometimes the action of the charcoal is prolonged beyond due limits, and in such cases the product becomes injured; to bring it back, the refiner strips it of the charcoal, and directs the blast upon it, in order to expel any carbon which might have been taken up. By operating in this way, and with great caution, the bath is ultimately brought to its greatest degree of malleability. This metal bears a very high character for its purity, but it is said that it never excels the *selected refined* of the English smelter.

Fig. 26.



The other form of the process is a remelting of the black copper in a reverberatory furnace; this, again, may be of two kinds. Figs. 26 and 27 illustrate one in which a blast is used as well to facilitate the refining, where O is the tuyere, B the elliptical bed, C C two receivers, and D the chimney.

Fig. 27.



About 3 tons of black copper make a charge; being melted, the impurities become oxidized and form a slag, which is raked away; when it is judged that this operation has gone far enough, the metal is led into the receivers, whence it is taken in the form of rosettes in the way described above. The other kind of reverberatory furnace used is similar to that in which refining is done during the English process; the operation, indeed, is here identical with that just named—first an oxidation is effected, and then poling is resorted to.

The other form of the process is a remelting of the black copper in a reverberatory furnace and poling, as in the sixth process of the English system. From this melting the copper is cast into various shapes to suit the wants of purchasers and manufacturers, and then may succeed the other processes of manufacture, as of rolling for the production of copper sheets.

An Older Form of the Mansfeld Process.—This, which now, we believe, is disused, is a different treatment of the *spurstein*, and itself results in *black copper;* it may therefore be said to stand for the fifth, sixth, seventh, and eighth operations described above.

First, the *spurstein* is roasted, not in a furnace but in kilns, as many as six consecutive times during a period of seven or eight weeks. Brushwood and charcoal being interlaid with it, air is conveyed to the lower part of the mass, to maintain the combustion, by channels made in the walls of the compartments where the process is carried on; these open inwardly at the bottom. The front wall of the kiln is composed of stone, built loosely, and with the view of keeping the charge in one compartment from intermixing with that in the opposite. When the matt has been calcined in the first of these apartments, it is transferred to the next, and there again interstratified with wood and charcoal as before; when the roasting is effected here, it is thrown into the third, and so on in rotation till it comes to the sixth, where the calcination is finished. The resulting product is called *gahrrost* by the Germans; it resembles in colour red copper ore, but sometimes it has a bluish-grey shade; it is brittle, and contains some of the copper reduced, and also more or less sulphate of copper, arising from the oxidation of the sulphur by the oxides. It is necessary to remove this by lixiviation, an operation which is carried on in a series of vats fixed in an incline, so that the liquor in the upper one flows into each in succession till it comes to the lowermost, and during its passage takes up as much of the salt as will make the solution so concentrated as to require very little evaporation to crystallize it. This washing is sometimes carried on after each roasting, and the sulphate of copper formed in each compartment extracted. Finally, the calcined matt is melted in the cupola furnace with about a quarter of its weight of the lixiviated matt from the first fusion, when this is of a good quality, one-sixth to one-tenth of its weight of rich copper slags, and a due admixture of charcoal or coke; the charge varies from 3 to 4 tons, and the period of smelting extends over twenty-four hours. This operation yields black copper, and a slag of various degrees of richness; but the former, being the heavier, sinks to the bottom of the crucible, from which it is removed in discs, as already described. The slag is subsequently roasted with other matt, and then smelted to divest it of the metal.

This black copper is, however, not that product of the same name, free from silver, which results from the eighth operation of the system as now carried on. The means by which the separation of the silver was done in this older system is one of extreme ingenuity and interest; one that deserves description, even though not at present practised. The principle of operation is that when copper is alloyed with lead, and afterwards heated to a certain point, the lead will separate and carry with it the silver, flowing away from the copper, which is left as a spongy mass; such a process is called *eliquation.* In practice it is done by fusing 3 parts of black copper and 10 or 12 parts of lead, or an equivalent proportion of litharge rich in silver, in a cupola furnace, and running the molten mass out into moulds, where it is rapidly cooled by means of water, and removed in the shape of discs of about an inch or less in thickness. These are then to be heated on a smelting hearth similar to that represented in Figs. 28 and 29 to the necessary degree, which determines the separation of the argentiferous lead by melting or sweating; this temperature is kept up as long as required. When as much as possible of the lead is removed the discs appear in their original form, but very porous, still retaining an appreciable amount of the alloyed metals.

The hearth is composed of two cast-iron plates resting upon ledges of brickwork, and inclined towards each other, leaving a space, S, under which is a hollow channel, c. The discs of alloyed metal are placed perpendicularly upon these plates, their contact being prevented by pieces of wood. Charcoal is then thrown around and between them, the dividers being withdrawn; this is afterwards ignited by introducing some lighted faggots into the channel, c, and the smoke and gases carried on through draught-holes or chimneys, *d d*, in the walls of the hearth. As the plates become heated, the lead begins to flow, and falls upon the floor of the channel, which, being inclined, conducts it to a receptacle, *b*, whence it is taken and cast into moulds. Heat is applied to the plates as long as any metal separates, and when no more exudes they are taken to another furnace in which the temperature is more elevated, and where any portions still retained are recovered, and the black copper is left purer than after the first heating. It still retains some lead, together with traces of silver, but the former is entirely dissipated in the refining to which the cakes are subjected.

Fig. 28.

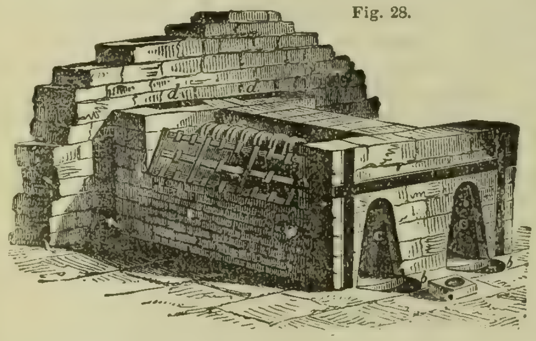
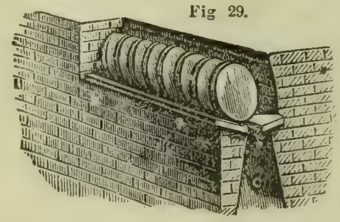


Fig 29.



Wet Processes.—These have of late years become increasingly important. On the one hand, large quantities of copper are now extracted by them from a product which till recently was not applied to the production of that metal, namely, burnt pyrites; and on the other poor ores have, with more or less of success, been subjected to such processes with the thought that copper can be more economically treated in the wet way than by the smelting processes hitherto described, so that poor ores might be utilized which otherwise would be counted quite unprofitable.

The wet process may be applied to ores which contain small quantities both of tin and copper, as well as an amount, large or small, of arsenic. In such cases all three products are obtained.

The ores are first calcined by one of the methods that have in detail been described in the article Arsenic. The calcined ore is then thrown into *laching* tanks, containing a strong solution of common salt; these tanks are square, and have a false bottom of perforated boards, over which is a layer of canvas for filtering; in the tank the brine is heated by means of steam, and then is drawn off to the *precipitating* tanks. By these means the copper is converted into a soluble form (chloride), and is taken up by the liquor; while, in the precipitating tanks, it is again brought down by scrap iron placed in them, which decomposes the salt of copper, and causes that metal to be deposited. The precipitated copper is removed by shaking and washing once a month, while the brine is run off to be again used with the addition of some fresh salt.

In this way ores that have but 2 per cent. of copper can be profitably treated. The amount of salt (old and fresh together) that is used is 2 cwts. to the ton of ore; but if there be over 3 per cent. of copper, then 2½ per cent. of salt is required.

By a late development of this system, the *nascent copper process*, any silver that may be contained in the ore, having been dissolved with the copper in the form of chloride (a compound that the brine will dissolve), is precipitated in the lower tanks by the copper *at the moment when the copper is released by the iron*. The precipitate then contains both the copper and the silver, which latter is separated by a distinct treatment, generally in another establishment. One example of precipitate gave 59½ per cent. of copper with 139 ozs. of silver to the ton, the rest being mostly iron.

If the ore contain tin, then the residue in the laching tanks is treated in the ordinary way for that metal.

Various processes have at different times been in use for the treatment of copper ores by *hydrochloric acid;* these, though to some extent successful, have not been completely so or permanently profitable.

Application of the Wet Process to Burnt Pyrites.—This process now constitutes one of the most important branches of manufacturing chemistry in this country, inasmuch as nearly the whole of the sulphuric acid made is produced from cupreous pyrites, the cinders from the pyrites kilns being subsequently sent to the copper extraction works. As appears by the "Mining Records" for 1873, 324,000 tons of *burnt coppery pyrites* were thus treated in that year; and this quantity is increasing steadily, more particularly since the Rio Tinto mines in Spain have been reopened on a very large scale, and their lessees are pushing the ore into the market, thus stimulating the manufacture both of sulphuric acid and of copper from the cinders. It may be considered as an established fact now, that for ores containing no more than 4 per cent. of copper the dry smelting process is not economical, and the wet extraction process is the only one practically used for it; but this result is certainly owing, to a great extent, to the possibility of recovering the iron as well as the copper by means of the wet process. Copper extraction by the wet process has thus become an appendage to sulphuric acid making, and it is naturally carried on extensively near the centres of that industry, that is, on the banks of the Tyne, in South Lancashire, near Glasgow, and near Birmingham. The process now carried out in all these localities is as follows:—

The three largest mines from which cupreous pyrites is exported to this country are those of San Domingos in Portugal, of Tharsis and of Rio Tinto in Spain. They all contain from 47 to 49 per cent. of sulphur, and, on an average—

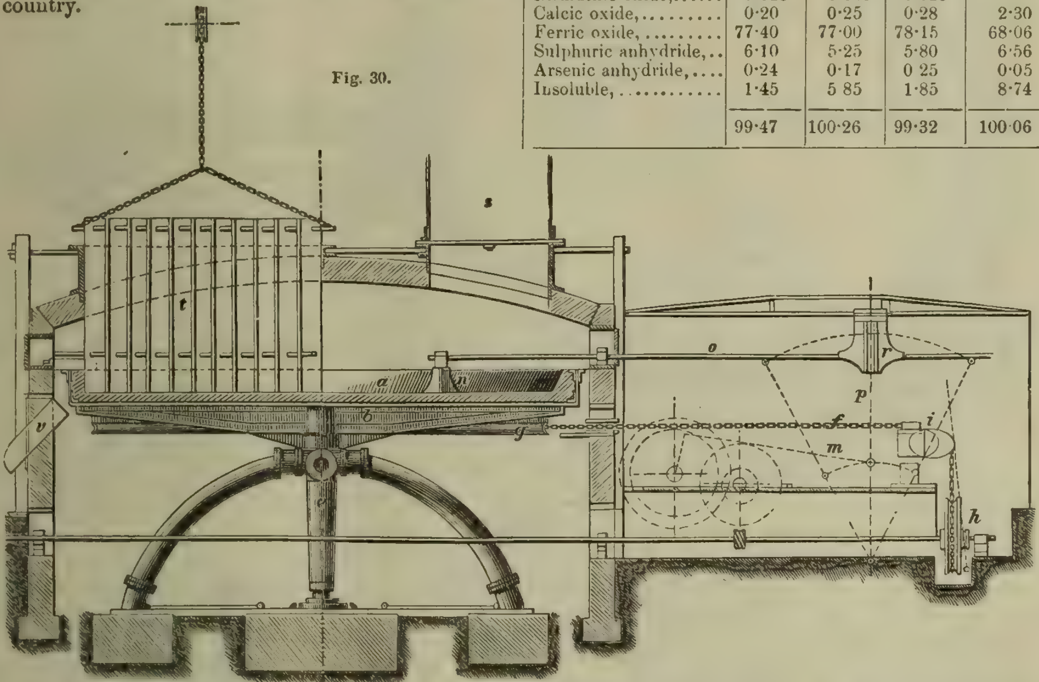
	Copper. Per cent.		Silver. Ounces per ton.
Rio Tinto, ...	3·80	....	1·20
Tharsis, ...	3·50	....	0·75
San Domingos, ...	3·70	....	0·75

There are several smaller mines in Spain and in Norway from which pyrites is also sent to this country.

As stated above, these ores are first used in the manufacture of sulphuric acid, both in alkali and manure works, the results being that the metallic sulphides are mostly converted into oxides. The following are analyses (according to Mr. GIBB) of the burnt ore from different sources:—

	Rio Tinto.	Tharsis.	San Domingos.	Ytteroen.
Copper, ⎧calculated⎫	1·65	1·50	1·55	1·01
Iron, ⎨as⎬	3·64	3·23	3·76	3·33
Sulphur, ⎩$Cu_2Fe_2S_3$,⎭	3·53	3·15	3·62	3·10
Cupric oxide, ...	2·75	2·56	2·70	0·39
Zincic oxide, ...	2·02	0·55	0·47	6·46
Plumbic oxide, ...	0·47	0·70	0·84	0·06
Silver, ...	0·0037	0·0023	0·0023	—
Cobaltic oxide, ...	0·007	0·032	0·033	—
Bismuthic oxide,......	0·013	0·010	0·013	—
Calcic oxide,.........	0·20	0·25	0·28	2·30
Ferric oxide, ...	77·40	77·00	78·15	68·06
Sulphuric anhydride,..	6·10	5·25	5·80	6·56
Arsenic anhydride,....	0·24	0·17	0 25	0·05
Insoluble, ...	1·45	5 85	1·85	8·74
	99·47	100·26	99·32	100·06

Fig. 30.



It must, however, be mentioned here, that the percentage of sulphur in burnt ores varies extremely, even in the same works, and to a very much larger extent from different works. Some are said to burn it down to 2 per cent., whilst others leave as much as 8 or 10 per cent. in the "cinders." The latter is excessively bad work, but from 4 to 5 per cent. sulphur is not considered excessive, and about as much or even more sulphur is really necessary for carrying out the wet copper extracting process. If the pyrites has been burnt too well, the copper extracting works have to add a little unburnt pyrites to the cinders, in order to have a sufficient quantity of sulphur present for the first stage of their process. It consists in calcining the burnt ore with sodium chloride (common salt) up to a certain point, viz., so far that the copper is nearly all converted into chloride, whilst as little as possible of the iron is converted into chloride, which would of course be soluble. The burnt ore is first of all crushed to a fine powder between fluted rolls, and the necessary quantity of salt (mostly in the shape of rock-salt) is added during the grinding. It amounts to from 10 to 20 parts for 100 cinders, for the ordinary furnaces worked by hand, but only to 7½ parts of salt for 100 cinders when intended for GIBB and GELSTHARPE's revolving cylinder. The mixture is sieved through a cylinder sieve covered with wire gauze of eight holes to the lineal inch, and run in iron wagons over the calcining furnaces, into which it is charged as required.

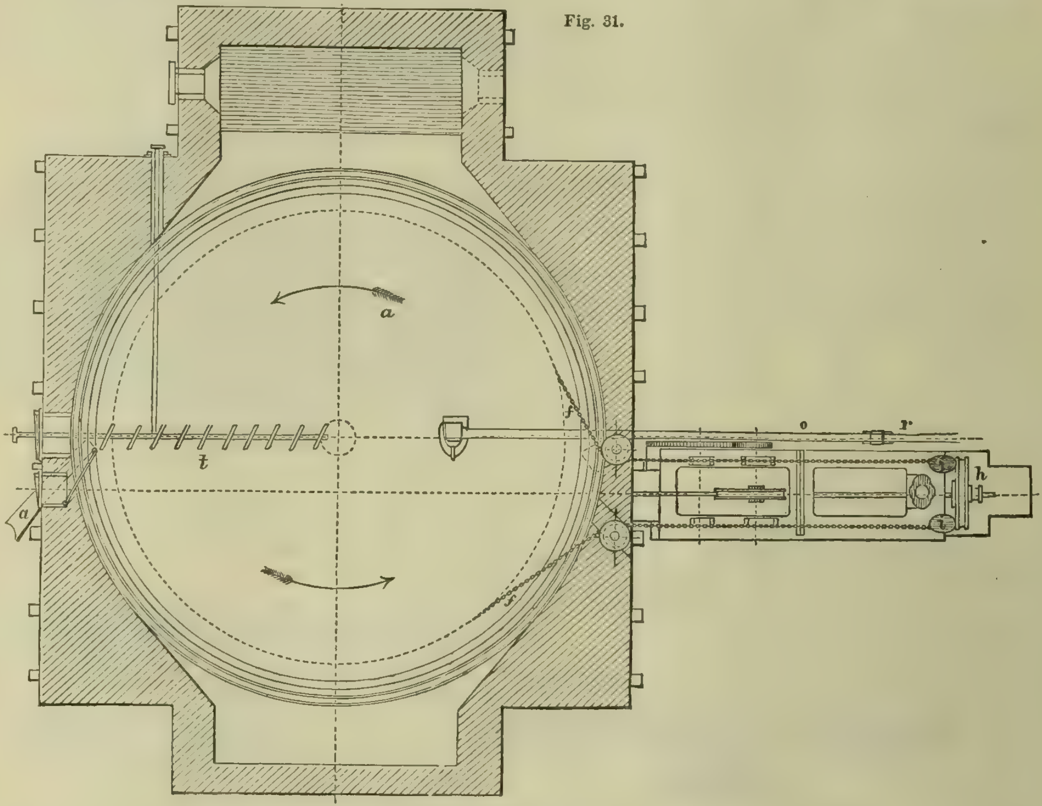
There is a great variety of calcining furnaces in existence, which can be classed under the following heads:—

1. *Reverberatory Furnaces of the Ordinary Kind.*—These were used at first, but have gone almost entirely out of use now.

2. *Mechanical Furnaces* (patented by GIBB & GELSTHARPE in 1872).—In these the hearth is formed of a circular cast-iron horizontal pan, kept constantly revolving, whilst the ore is turned over and exposed to the oxidizing flame of the furnace by a

plough reciprocating slowly in a radial line of the circle of the bottom. The revolution of the pan and motion of the plough are both attained by simple gearing from one shaft. Arrangements are provided for discharging the ore by the revolution of the hearth, so that but little manual labour is required, except for firing. This kind of furnace is illustrated on Figs. 30 to 33, and its different parts can be easily recognized in the diagrams. The diameter of the pan, *a*, forming the furnace-hearth is 16 feet;

Fig. 31.



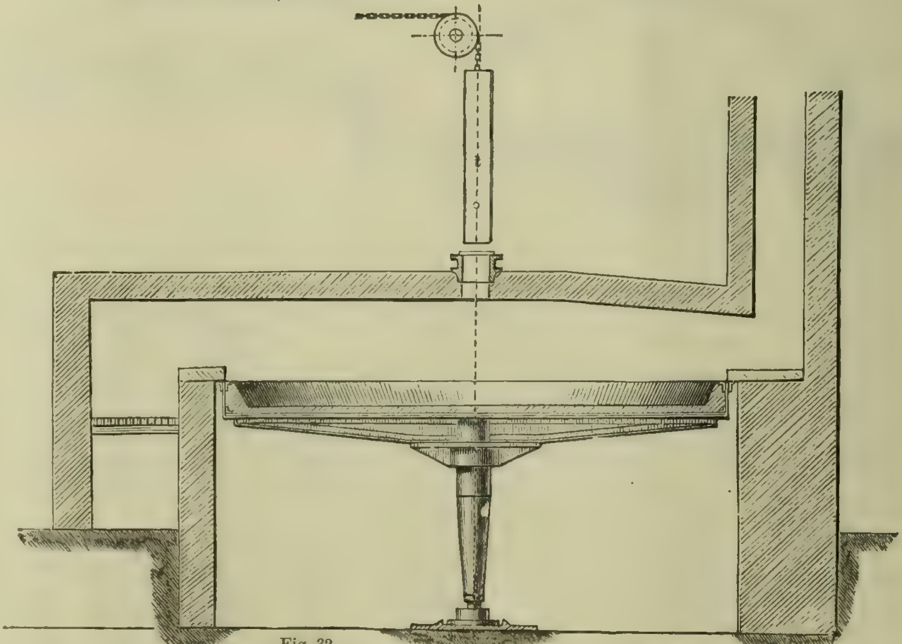
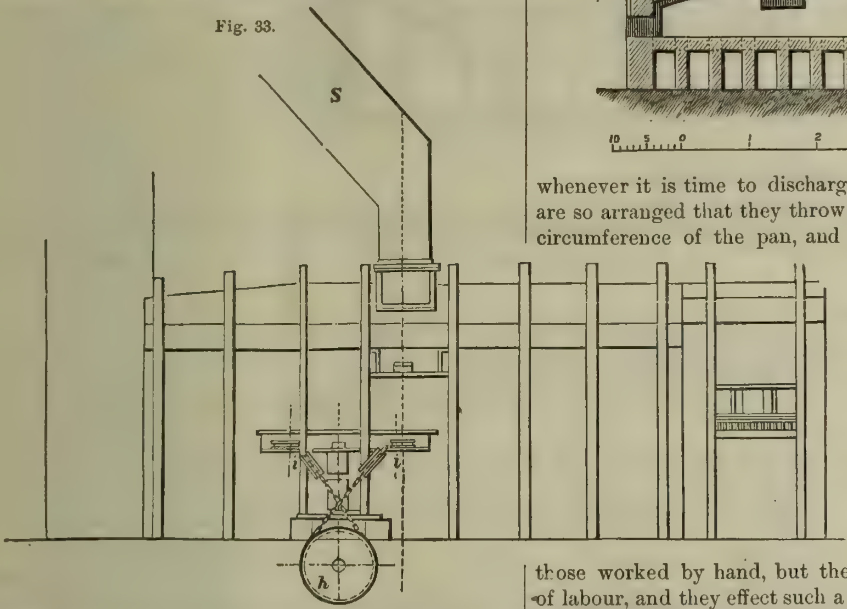


Fig. 32.

it is lined with firebricks and carried by radial girders, *b*, attached to a vertical shaft, *e*. The pan revolves round its vertical axis by means of an endless chain, *f*, running on a pulley, *g*, underneath the pan, and set in motion by suitable gearing from a horizontal shaft, *h*, running outside the furnace. From the same shaft is derived the reciprocating motion of the plough, *n*, working inside the furnace, by means of the cross-head, *r*, and the rod, *o*, and the gearing *m*, *i*, *p*. The gearing is so arranged that, during each revolution of the pan, the plough is only moved forward or backward to the extent of its own width, so that every part of the hearth is worked up by it. The diagrams also show the charging hopper, *s*, and the discharging plates, *t*, which are let down by means of a chain and pulley whenever it is time to discharge the furnace; they are so arranged that they throw the ore towards the circumference of the pan, and ultimately out of it through a shoot, *v*, on to the floor. As soon as this is completed they are drawn up again, and the opening through which they had passed is closed by a damper.

Fig. 33.



Figs. 34, 35.

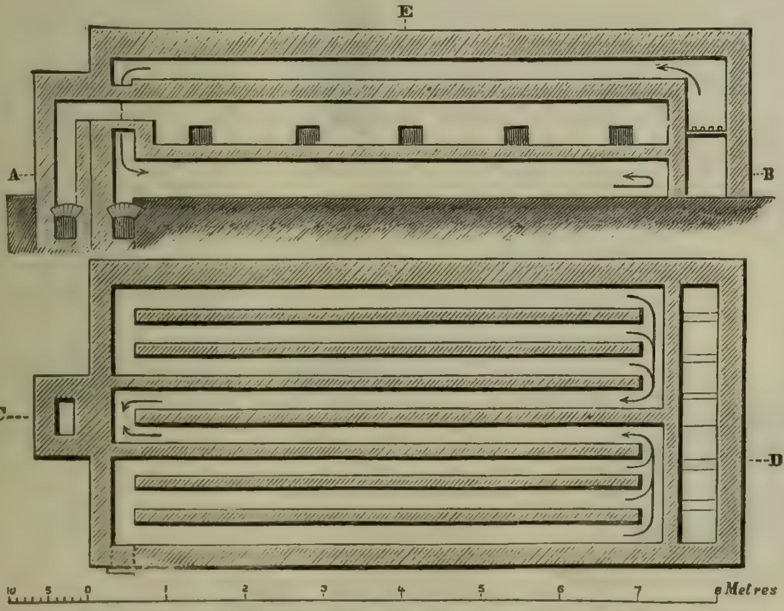
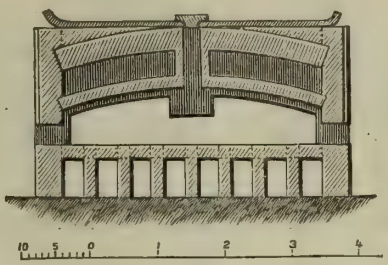


Fig. 36.



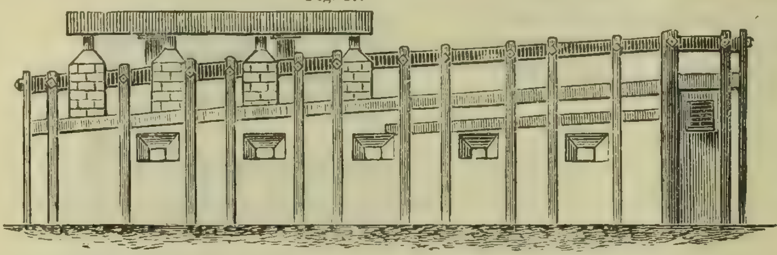
These furnaces are, of course, much more expensive than those worked by hand, but they save a great deal of labour, and they effect such a complete calcination that they would appear to be the most efficient of all. There are twelve of them in use at the Bede Metal Works at Hebburn-on-Tyne.

3. *Close Furnaces.*—In these the flame is not in direct contact with the ore, but the latter is heated by a large muffle through the brick work; the fire passes both over the arch forming the roof and under the bed forming the bottom of the muffle, and the air required for oxidation only enters through the working doors. This kind of furnace is used at all the works owned by the Tharsis Sulphur and Copper Company, and is shown in Figs. 34, 35, 36. Fig. 34 is a longitudinal section on line of C—D (Fig. 35); Fig. 35, a plan on line of A—B (Fig. 34); and Fig. 36, a cross section on line E—F (Fig. 34).

4. *Combined Furnaces*, in which the bed for one half of its length is protected by a curtained arch, so that the bed remote from the fire can be kept at

a fair working heat without overheating the bed nearer the bridge. In this furnace the flame, after passing over the working bed, returns under it in flues, over which the bed is formed by tiles. These furnaces are about 20 feet long and 9 feet wide; they are in use at the Bede Metal Works, and are also shown on Figs. 37, 38, 39, 40. Fig. 37 is an elevation; Fig. 38, longitudinal section; Fig. 39, a plan of working bed level; and Fig, 40, a cross section on line, A—B, Fig. 39.

Fig. 37.



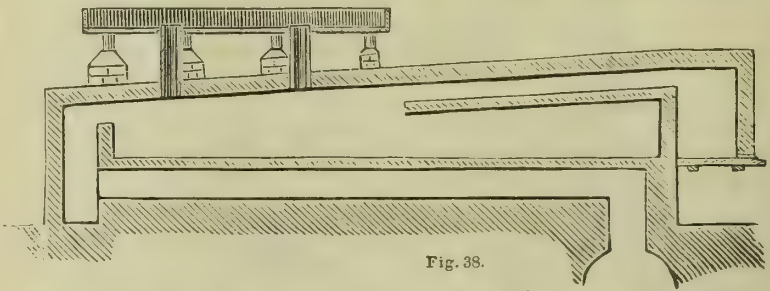


Fig. 38.

Fig. 39.

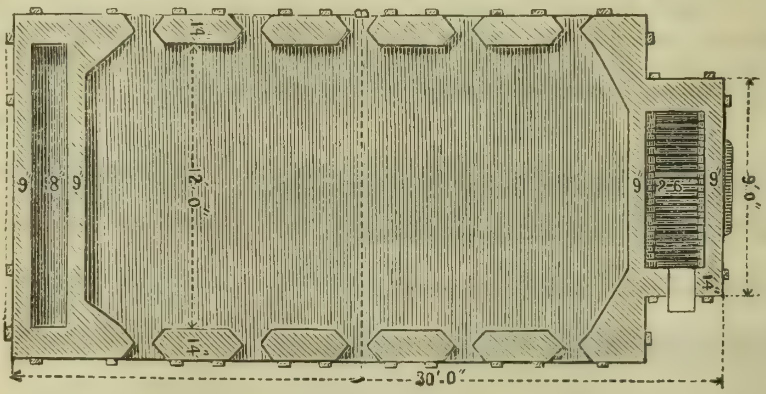
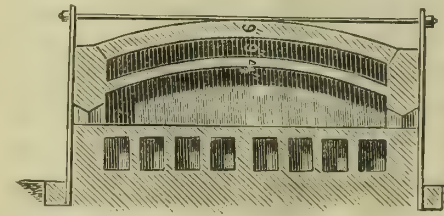


Fig. 40.



5. *Open Reverberatory Furnaces*, about 30 feet long by 11 feet wide, heated by gas produced in Siemens' generators; the gas is burnt first in flues under tiles forming the bed of the furnace, and after this the flame is carried over the same bed in direct contact with the ore. These furnaces are used by the Widnes Metal Company and several other firms in Lancashire and Cheshire; they are shown in the diagrams, Figs. 41, 42, 43, 44. Fig. 41 is a longitudinal section on line C—D (Fig. 42); Fig. 42, a plan on line A—B (Fig 41); Fig. 43, a front elevation; and Fig. 44, a back elevation.

Whatever furnace may be used, the object of the operation is always that of oxidizing the burnt ore completely, in such a manner that the copper is as much as possible converted into sulphate, which is further converted into chloride by means of the rock salt, sodium sulphate being produced at the same time. Experience has shown that mere calcining, without sodium chloride, never renders the whole or even the larger portion of the copper soluble (as sulphate). Even in calcining with salt a certain portion of the copper always remains as oxide; but the largest portion of this is recovered by using hydrochloric acid in the subsequent lixiviation.

The following table gives a good idea of the result of the calcination, according to Gibb's analyses:—

	Gas Furnace.		Close Furnace.		Mechanical Furnace.	
	P. cent.	Cu. P. cent.	P. cent.	Cu. P. cent.	P. cent.	Cu. P. cent.
Cupric chloride,...	4·03 =	1·90	4·25 =	2·00	6·70 =	3·15
Cuprous chloride,..	·32 =	·20	·35 =	·21	nil.	
Cupric oxide......	1·26 =	1·00	·88 =	·70	·32 =	·25
Sodium chloride,..	2·50		3·40		0·90	
Sodium sulphate,..	13·18		17·40		14·03	
Insoluble copper,..		·15		·12		·13
Total copper,.....		3·25		3·03		3·53

The main point to be observed is always that as little as possible of the copper should remain insoluble in water and dilute acid; in the above samples this amounts to ·12 to ·15 per cent. on the burnt ore; but when using ores rich in copper or badly burnt, the proportion of insoluble copper becomes much greater and the loss more serious. It is contended for the close furnace that the proportion of insoluble copper is rather less than with open calciners; but this seems to be more than compensated by a greater expenditure of fuel. The greatest advantage is attained by the mechanical furnace; this is easy to understand, as the best calcination should combine an equable low red heat with continual stirring, in which respect no furnace can compare with Gibb and Gelstharpe's. With this furnace next to no cupreous chloride is formed, and the proportion of cupric oxide, however refractory, badly burnt, or rich in copper the ores may be, rarely exceeds ¼th per cent.

Fig. 41.

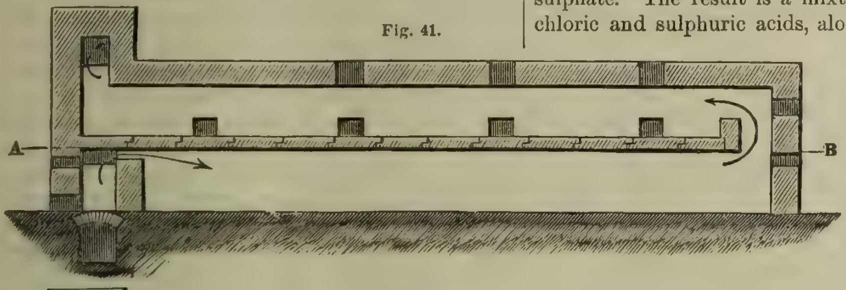


Fig. 42.

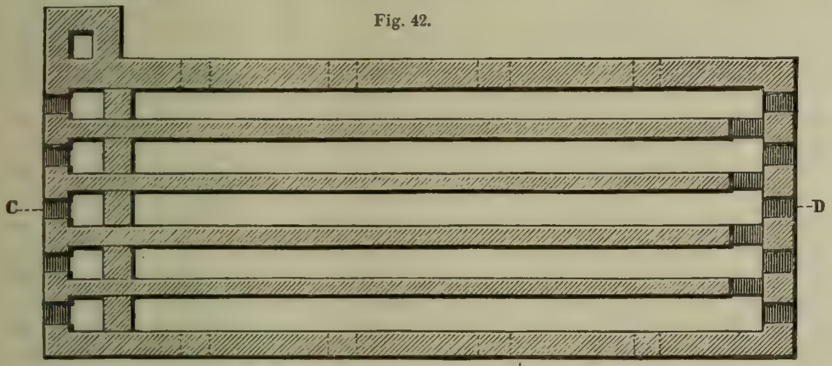


Fig. 43.

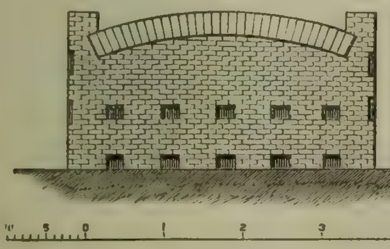
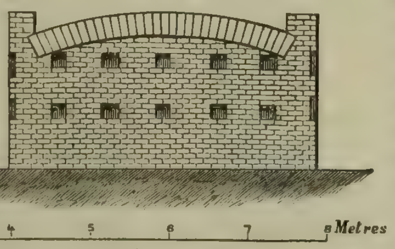


Fig. 44.



The usual weight of the charges is: for the mechanical furnaces, 5 tons of ore (time of calcining, nine hours); for the open furnace with curtain arch, 56 cwts. (time of calcining, eight hours); for the gas furnace, about the same; the close calciners take more time.

During the calcination a great deal of gas is evolved, principally sulphurous and sulphuric anhydride, hydrochloric acid, and chlorine. These are mixed with the gas from the fire, except in the case of close calciners, and they are passed through condensing towers packed with coke, over which a constant stream of water is kept running, exactly similar to those used in the manufacture of sodium sulphate. The result is a mixture of dilute hydrochloric and sulphuric acids, along with a small proportion of volatilized metallic chlorides. These are not lost, as the liquid from the condensers is very usefully employed in the subsequent process of lixiviation, when its acids reduce the larger proportion of the cupric oxide to the soluble state.

The next step in the process is the *lixiviation* of the calcined mixture. It is carried out in square wooden tanks, 10 to 12 feet square and 4 feet deep, in which the ore is placed on a filter formed of heather and straw, or in some similar way, by successive washings with hot water, which in percolating the ore dissolves the soluble salts. The water is followed by the weak acid from the condensers, or if this should not be sufficient, by ordinary hydrochloric acid, and finally hot water is used again till the ore is exhausted. It is usual to pump up (or preferably, to blow up by means of an injector) the last washings of one set of tanks to serve for the first washings of the next set, in order to obtain a more concentrated solution of copper. The solutions contain, besides copper and other salts, also silver and gold, which are sometimes recovered by special processes, as will be mentioned hereafter. Arsenic, bismuth, and lead are also present, partly dissolved out of the calcined ore, and partly from the acid used in lixiviation, more particularly when the acid condensed from the calcining furnace gas has been employed for this purpose.

It is the value of the residue from the lixiviation which makes the wet copper process more economical than the dry processes for poor cupreous ores; since it constitutes an iron ore of considerable value, known as "purple ore," or sometimes as "blue billy." Mr. Gibb gives the following analysis of two fairly typical specimens:—

Ferric oxide,	90·61	95·10
Copper,	·15	·18
Sulphur,	·08	·07
Phosphorus,	Nil	Nil
Lead sulphate,	1·46	1·29
Calcium sulphate,	·37	·49
Sodium sulphate,	·37	·29
Sodium chloride,	·28	—
Insoluble residue,	6·30	2·13
	99·61	99·55
Metallic iron,	63·42	66·57

This ore, it will be observed, is almost entirely free from sulphides and entirely so from phosphorous, and very rich in iron; its only drawback is this, that it is in the state of powder, which greatly militates against its use in the blast furnace. It has been attempted to mould it into bricks of sufficient coherency to allow of their being introduced into the blast furnace, but this raises the cost too much; in some cases it is also used direct in its pulverulent state in the blast furnace, but its main employment is for "fettling" the hearths of puddling furnaces, for which object it is eminently adapted and mostly used. Its direct conversion into malleable iron or steel has not yet been carried out successfully on a large scale.

The liquors obtained by lixiviating the calcined ores must now be submitted to the process of *precipitation.* It will, however, be useful to first give a table showing the action of water and dilute acid on the calcined ores, according to Mr. Gibb; this table will at the same time show the great difference between the mechanical and the hand-worked furnaces:—

	Mechanical Furnace.		Hand Furnace.	
		Per cent. Cu.		Per cent. Cu.
Soluble in Water—				
Cupric chloride,	4·16	1·96	3·81	1·82
Cupreous chloride,	Nil	—	·19	·12
Cupric sulphate,	1·83	·81	Nil	—
Ferrous sulphate,	·15	—	Nil	—
Ferric sulphate,	·75	—	Nil	—
Zinc sulphate,	2·01	—	1·95	—
Calcium sulphate,	1·29	—	1·39	—
Sodium sulphate,	9·17	—	11·13	—
Sodium chloride,	Nil	—	2·64	—
Soluble in dilute hydrochloric acid—				
Cupreous chloride,	·015	·10	·33	·21
Cupric oxide,	·225	·18	1·01	·81
Lead sulphate, Ferric oxide,	Not estimated		Not estimated	
Residue (by difference) = purple iron,	80·40	·08	77·55	·11
	100 00	3·04	100·00	3·07

The fact that the more complete action of the mechanical furnaces produces almost pure sodium sulphate (free from chloride) induced Mr. Gibb to propose a most ingenious plan for utilizing the same, which unfortunately has never been carried out to a commercially successful end, although it was at work on a very large scale for some time. It consisted in precipitating the copper liquors by means of sulphuretted hydrogen obtained in a subsequent stage of the process; the cupric sulphide was separated by a filter press and smelted in the usual way. The acid liquor remaining was boiled down to dryness, the residue mixed with small coals and furnaced, by which means the sodium sulphate was almost entirely reduced to sulphide; the furnaced mass was lixiviated with warm water and the solution treated with carbonic anhydride, produced by the burning of coke; the sulphuretted hydrogen evolved in the operation was utilized for precipitating the copper liquors, as mentioned above, and the remaining solution of sodium carbonate was boiled down to dryness and calcined in the usual way, thus yielding commercial soda ash. This process having been given up, there is at present no process actually at work for utilizing the sodium sulphate in the copper liquors, or for precipitating them in any other way than by means of *metallic iron.* This is usually employed in the form of scrap iron, but for this can be substituted with very great advantage the "spongy" iron, obtained by reducing purple ore with coal in a specially constructed furnace, which is shown in Plate I., Copper. The flame heats the mixture both from underneath, through the bed constructed of tiles, and by direct contact from above. The furnace has a very deep hearth, and its working doors are usually kept tightly luted, to avoid the re-oxidation of the reduced iron; the process of reduction lasts from nine to eighteen hours, and after its termination the ore is drawn into air-tight boxes, by means of iron pipes passing through the furnace bed and the flues underneath into a place provided for the purpose. The boxes are immediately closed, and only opened when their contents are completely cooled down, so that the spongy iron is not subject to instant re-oxidation, as it would be if exposed to the air in the hot state. It is ground to powder and effects the precipitation of the copper almost instantaneously, whilst scrap iron takes a long time to perform its work. The following are analyses (by Gibb) of copper precipitate obtained by various kinds of iron, so far as the most important constituents are concerned:—

	Precipitated with		
	Spongy Iron.	Heavy Scrap.	Light Scrap.
	Per cent.	Per cent.	Per cent.
Copper,	67·50	72·50	67·50
Arsenic,	·137	·306	·100
Silver,	·011	·046	·066
Lead,	1·30	2·60	1·74
Ferric oxide,	5·15	4·41	7·56
Carbon,	5·10	—	—
Silica,	3·20	—	—

This precipitate is either sold to copper smelters, who smelt it advantageously with copper regulus, or it is smelted by itself in the extracting works. In the latter case it is charged into reverberatory furnaces, similar in every way to the ordinary copper-smelting furnaces. When run down the slag is skimmed off and the copper tapped into sand pig moulds as blister copper. When, however, spongy iron has been used, the carbon in excess prevents the copper being melted directly to blister, and about one half of the precipitate is therefore calcined in large calciners, exactly like those used for calcining burnt ore with salt. The carbon is here burnt off and the copper partially oxidized; the product is mixed with raw precipitate, and can now be smelted as usual. The slag is skimmed off and the copper tapped as blister. The slag contains from 3 to 10 per cent. of copper, which are recovered by smelting with raw ores, producing "coarse metal" (sulphide of copper and iron containing about 30 per cent. of copper), and this is brought forward to copper by calcining, smelting, and washing in the ordinary way. The blister copper made from the precipitate is refined by roasting, to oxidize the iron, sulphur, &c., which it may contain, followed by reduction of the cupric oxide produced in roasting by charcoal, and poling in the way usually employed by the copper smelter.

The copper produced is pure and tough, and an easily marketable article. The following analyses will show its impurities compared with those of English copper made by the ordinary mode of smelting:—

	Copper from Wet Process.		"English" Copper. FIELD'S Analyses.	
	Per cent.	Per cent.	B. S. Per cent.	Tough. Per cent.
Silver, ...	·022	·016	·035	·047
Arsenic, ...	·030	·170	·105	·090
Antimony, ...	none.	trace.	·010	trace.
Bismuth, ...	·006	·019	·035	·130
Lead, ...	none.	·002	none.	—

Treatment for Silver.—It has been mentioned above that the solutions obtained in lixiviating calcined ores contain silver and gold, certainly in very small quantities, viz., about 14 dwts. of silver and 2 or 3 grains of gold to the ton of burnt ore. But even these proportions, especially that of the silver, are not too small to prevent the precious metals from being recovered, and two methods are actually in use for this purpose at this moment.

That of Claudet, used by the Widnes Metal Company, Lancashire, is founded upon the insolubility of silver iodide in solutions of chlorides. The copper liquor, previously to being precipitated with iron, is run into separate vessels, where a solution of potassium iodide, exactly equivalent to the silver present, is mixed with it and allowed to stand for two or three days. The silver iodide is precipitated, and settles at the bottom of the tank, the clear liquor is run off to undergo the iron treatment, and fresh liquor direct from the lixiviating tanks run into the desilverizing tank, to be treated with iodide. The silver iodide, accumulated by a number of successive precipitations in the same tank, is removed, washed, and decomposed by metallic zinc; this results in the formation of metallic silver and of zinc iodide, the latter being available for further operations in the place of potassium iodide. The silver is certainly not pure, but in the form of a residue containing 5 to 6 per cent. of metallic silver and about ·06 per cent. of gold, the bulk of it being lead, zinc oxide, calcium sulphate, &c. Only the first three washings of the burnt ore are submitted to Claudet's process, as they contain 95 per cent. of the silver.

Gibb's process depends on the fact that, when sulphuretted hydrogen is passed through a copper solution containing a small proportion of silver, the latter metal is at first precipitated in a much larger proportion than the former; when 6 per cent. of the copper have been precipitated, the great bulk of the silver has also been thrown down as sulphide, and is therefore concentrated in the upper precipitate. The sulphuretted hydrogen is generated by the action of hydrochloric acid on the "tank waste" of alkali works, and blown into wooden tanks containing the copper solution, along with a large quantity of air purposely drawn in for dilution, generally for twenty minutes, till by a rough testing (with potassium cyanide) it is ascertained that 6 per cent. of the copper are precipitated. Whilst the copper obtained without any desilverizing process contains on an average 20 ozs. silver per ton, the 6 per cent. precipitated as above contain 200 ozs. silver per ton of copper; the copper made from the residual liquid only contains 3 ozs. silver per ton. The precipitate of cupric and argentic sulphide is washed and pressed in a Needham's filter press; it is then calcined at a low temperature in a furnace exactly similar to those serving for the calcining of burnt ores with salt. In this operation chlorides of silver and copper are produced with oxide and sulphate of copper. The calcined precipitate is ground to a coarse powder and lixiviated; the cupric sulphate is dissolved along with a mere trace of silver (1 oz. per ton) and added to the ordinary copper liquors. The residue remaining in the lixiviating vessel is now treated with a hot solution of common salt, which dissolves out the silver chloride, along with some copper and lead; the residue only contains from 3 to 4 ozs. of silver per ton of copper, and is smelted as usual. The solution of chlorides is mixed with milk of lime, which precipitates all the metals; the precipitate is well washed, to free it from calcium chloride, and then digested with dilute sulphuric acid to dissolve the copper, and again washed. After drying the residue has the following composition:—

Silver, ...	8·77
Lead oxide, ...	28·66
Cupric oxide, ...	3·75
Ferric oxide, ...	2·61
Calcium oxide, ...	13·67
Sulphuric anhydride, ...	31·72
Chlorine, ...	4·70
Water, ...	4·20
Insoluble, ...	1·40
	99·48

It is sent to Birmingham and used by the silver smelters there. By either process about 1 part silver on 60,000 of burnt ore, equal to 2*s.* 6*d.* per ton, is recovered at a cost of about 10*d.* per ton of ore worked; and looking at the very large quantity of burnt ores worked up, this saving is not inconsiderable.

The Lime Process.—A scheme has lately been put forward under this name for the treatment of the poorer ores of the Snowdon Copper Mining Co., which requires to be tested by experience before much can be said of its merits. The ore is crushed and mixed with a small quantity of lime, and made up into cakes of a convenient shape for stacking in a kiln; these are then burnt at a low red heat with but little expenditure of fuel; the roasted ore being crushed and lixiviated with either water or an acid liquor collected from the kilns. The copper is said to be converted from its original form of sulphide to sulphate of copper, which is soluble; from the solution copper sulphide can again be obtained by means of sulphuretted hydrogen, the difference being that it is now concentrated, and in a form from which the copper may easily be smelted.

Copper Assaying: Dry Way.—For the purposes of assaying copper ores may be divided into four classes. These may usually be distinguished by inspection, or a sample may be washed and by that means the composition approximately guessed at. On the determination of the class of ore it belongs to will depend its treatment in the assaying. The following are the classes:—

First Class.—Native copper, which only requires to be remelted to be fit for the market.

Second Class.—Ores not containing sulphur, namely, oxides, carbonates, silicate, and chloride; these require simple reduction and the refining of the coarse metal reduced.

Third Class.—Ores containing sulphur, but with a large percentage of copper and not much iron. These require to be roasted "dead," then to be fused for the reduction of the metal, this to be followed by refining of the coarse metal obtained.

Fourth Class.—Less rich ores, containing sulphur and iron in considerable quantity, and a large proportion of earthy impurities. To this class belong the greater part of the Cornish ores. For these an additional fusion for "regulus" is wanted, as will be shown in detail below, where the processes described apply chiefly to this fourth class, while for the three former classes some of the earlier operations should be left out as above indicated.

To conduct an assay of copper, a furnace capable of producing a high degree of heat is indispensable; one well adapted to the purpose is represented in Fig. 45. In this sketch, the space A is assigned to the fuel and crucibles wherein the reduction is to be effected; this may be 16 inches in depth, from the level of the cover, E F, to the grate, and from 8 to 10 inches in breadth. C is the ashpit, which is slightly raised from the floor-level, to facilitate the removal of the cinders; the bars of the grate are introduced through the opening, D, the further end resting upon a proper support fixed in the walls of the furnace. B is the chimney, which should be sufficiently capacious to carry off all the products of the combustion; and it should be entirely kept apart from any other opening. The draught is regulated by the damper, G, which can be pushed in or drawn out by an iron handle. The crucible and assay are introduced into the furnace at the mouth, E F, and placed upon pedestals of brickwork, resting upon the bars of the furnace, after which the opening is closed by the tile, as seen in the figure. To prevent cracks or fissures forming in the walls of the furnace, by repeated expansion and contraction of the material as it is heated, they are coated over with plates of stout sheet-iron, riveted together, and, if necessary, bound by hoops of metal.

Besides this, the most important part of the arrangements for assaying, other apparatus, none of it, however, very complicated, is required—the various utensils for holding the crucibles, for stirring the ore within them during the roasting processes, moulds in which to form the assay, &c. The best fuel to use is coke broken into pieces about the size of an egg. If the ore has less than 10 per cent. of copper, 400 grains of it are taken; for a greater percentage (10 to 30 per cent.), but 200 grains; and if still richer ores, 100 grains. The ore, finely powdered, is first roasted in a crucible at a dull red heat, being stirred continually till a portion of the sulphur is expelled; the pot is then taken from the fire, and allowed to cool gradually. If the assay has a reddish appearance on the top, and a blackish underneath, the process is properly executed. The same crucible being preserved for the next process, the roasted ore is now mixed with the fluxes—borax, lime, and fluor spar—in proportions which must vary with the samples according to the character of the earthy materials contained in the ore, and a layer of salt is put over all. A not uncommon plan is to dispense with the previous roasting, and at this stage add nitre to the previously named fluxes, this being an oxidizing agent, whose action will stand in place of that of the air. The crucible being heated gently all round by coke, which when ignited still completely surrounds it, a red heat is gradually attained and

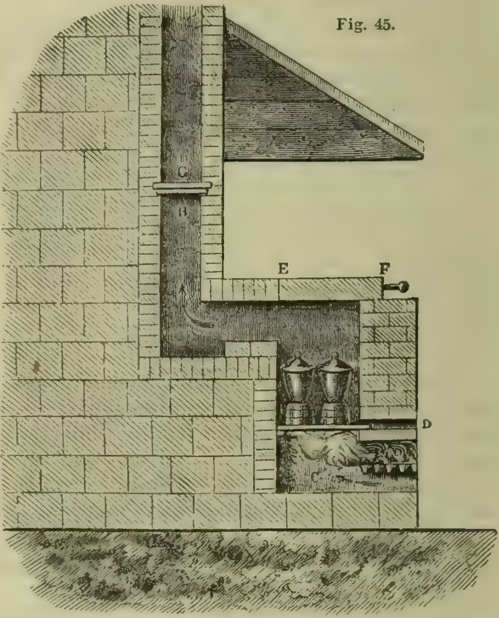


Fig. 45.

kept up for about a quarter of an hour. When effervescence through the slag has ceased the operation is complete; the contents are then quickly poured out into an iron mould, whence they are transferred to water while still hot for the purpose of cracking the slag, and enabling it to be separated from the button of regulus. This regulus is a disulphide of copper, combined with sulphide of iron, copper being present to the amount of about 60 per cent.

The regulus is next roasted in order to dissipate all the sulphur in the form of sulphurous acid, and to bring the copper to protoxide and the iron to peroxide. For this purpose the button is ground to fine powder, and placed in a smaller crucible; several such roastings can be carried on in one furnace at the same time. The assay is heated first to a low red heat, and afterwards to a bright red heat; it is continually stirred in the early part of the operation and occasionally later on; after half an hour or so all the sulphur will have been driven off, and the calcination will be complete.

Fusion of the regulus is the next step; the object being to reduce the oxide of copper to the metallic state, and to bring the iron to such a condition (protoxide) as will enable it to be taken up by the fluxes. The flux chiefly used is a mixture of tartar and nitre with, in some cases, the addition of borax; sometimes charcoal and carbonate of soda are employed: in any case the flux must perform the two functions of reducing the oxides and dissolving the iron protoxide. The same crucible is used that the calcination was done in; a bright red heat is required, first fusion occurs, and afterwards effervescence. When the effervescence ceases the operation is complete, and all is poured together into a mould, where the button of *coarse copper* is found separate from the slag, which, however, may contain a small quantity of the metal, which can be obtained by a separate fusion, the weight being added to that of the main portion of the assay.

One more operation is, however, necessary; this is *refining* the coarse copper. The crucible used in the last operation being heated to redness the button of copper is dropped in, it soon melts and is acted on by the air so far as to have its impurities oxidized; when the surface of the melted metal has become quite bright some refining flux (a deflagrated mixture of nitre, cream of tartar, and salt) is poured on, and after a couple of minutes the whole contents are poured into a mould, and a button of *fine copper* is obtained. The slag from this, as well as the slag from the coarse copper, being now ground and melted together, with the addition of charcoal, some small beads (called *prills*) of copper will be obtained, whose weight, as stated above, must be added to that of the larger button.

It will be seen that this long process of assay is but a rehearsal, so to say, on a small scale, of the Swansea copper smelting. The results it gives are quite comparable with the yield that may be expected in the smelting itself, the sources of error being similar in both operations: hence it is the universally accepted mode of testing copper ores followed by practical men. Chemical processes are far more accurate; but dry assay shows not the true amount of copper contained in an ore, but the true amount which can be extracted from it by smelting.

Copper Assaying: Wet Way.—The process used at the Mansfield Copper Works is as follows (according to THORPE):—About 5 grms. of the finely powdered ore are weighed out into a flask and mixed with 40 c.c. of hydrochloric acid of about 1·16 spec. grav., 6 c.c. dilute nitric acid (made by mixing equal bulks of water and pure acid of spec. grav. 42) are added, and the flask is gently heated for thirty minutes on a sand bath, after which it is boiled for fifteen minutes. The whole of the copper is now in solution; the extraction is complete, even in the case of very rich ores, provided sufficient attention has been paid to the powdering. The solution is filtered into a large beaker, into which a rod of zinc, weighing about 50 grms. and surrounded with a piece of thick platinum foil, has been previously placed. It is necessary that the zinc employed should be as free as possible from lead. The precipitation of the metallic copper commences immediately, and is generally complete in about half an hour. The rod of zinc is withdrawn, and the precipitated copper repeatedly washed by decantation. If the amount of the copper does not exceed 6 per cent. (which may be approximately known from the bulk of the reduced metal) it is dissolved in 8 c.c. of the dilute nitric acid, prepared as above. The beaker is gently warmed, and the amount of copper in the liquid titrated by a solution of potassium cyanide, after previous addition of ammonia solution, prepared by diluting 1 volume of ammonia-water (sp. gr. 0·93) with 2 volumes of water. When the amount of copper in the ore exceeds 6 per cent., the metal is dissolved in 16 c.c. of the nitric acid solution, and the liquid is washed into a 100 c.c. flask, diluted to the mark, shaken, 50 c.c. withdrawn, mixed with 10 c.c. of the dilute ammonia, and titrated with potassium cyanide, according to PARKES' process.

When a solution of potassium cyanide is mixed with an ammoniacal solution of cupric sulphate or nitrate, the azure colour gradually disappears with the formation of copper-ammonium cyanide, free ammonium cyanide, ammonium formate and urea. The reaction is only constant so long as the amount of free and combined ammonia present is invariable.

The strength of the solution of the potassium cyanide is tested thus:—Exactly 5 grms. of chemically pure copper, prepared by the electrotype process, are weighed out into a litre flask and dissolved at a gentle heat in 266·6 c.c. of the nitric acid, prepared as above. On cooling, the solution is diluted to the mark; 30 c.c. of this solution, containing 0·15 grms. of metallic copper, are placed in a beaker and mixed with 10 c.c. of the dilute ammonia liquid, and the solution of potassium cyanide is added from a burette, with constant stirring, until the blue colour of the liquid just disappears. The strength of the cyanide should be so arranged that 1 c.c. of the solution is equivalent to 5 milligrammes of copper.

The titration of the solution of the sample of ore is made in exactly the same manner. If exactly 5 grms. have been taken, and the cyanide is of the above strength, each cubic centimètre of the solution required for decolorisation is equivalent to 0·1 per cent. of copper. The number of cubic centimètres needed, divided by 10, gives the percentage of copper at once.

This method is very expeditious and at the same time accurate, if due care be exercised, and if the titrations are always made under similar circumstances. The presence of a very small quantity of lead, arsenic, or antimony, does not influence the results, but zinc, nickel, and cobalt are more injurious. The precipitated copper must, therefore, be washed thoroughly before dissolving it in nitric acid. The solutions must be quite cold before titration, since less potassium cyanide is needed to decolorise a solution when warm than when cold. The standard solution of potassium cyanide requires to be titrated from time to time, since its strength is not invariable.

Another method is the Swedish one, precipitating the copper by metallic iron and weighing it. The presence of any metal not precipitable by iron is of no consequence in this case; nor is that of lead, tin, and antimony, which remain behind in dissolving, but arsenic must be separated as sulphide. The ore is decomposed with aqua regia, sulphuric acid is added, and the whole evaporated till all nitric acid is driven off; the residue is dissolved in water with a few drops of sulphuric acid and filtered; a few pieces of clean iron wire are added, and the whole gently heated. The copper is precipitated in a spongy form; it is washed off the iron, the liquid part decanted along with any carbon from the iron floating in it, and the copper gently dried and weighed. This process becomes much more exact by using pure zinc in the place of the iron, but it takes much longer time in that case; on the other hand, Luckow has described a process for separating the copper by the galvanic current, which is done very quickly and produces it in a consistent and not easily oxidisable form.

A very exact mode of wet assay for copper is the precipitation as sulphide by sulphuretted hydrogen or sodium hyposulphite; the cupric sulphide is ignited with exclusion of the air, and thus converted into cuprous sulphide (Cu_2S), 100 parts of which contain 79·85 per cent. of copper. All metals which are not precipitated from their acid solutions by sulphuretted hydrogen are quite harmless in this case, as well as lead which remains behind in dissolving; mercuric and arsenic sulphide are volatilized in igniting, and only antimony and tin, if present, require a special treatment.

The same precipitation has been utilized by Pelouze for a volumetrical estimation of copper in an ammoniacal solution, by means of a solution of sodium sulphide. The latter is run from a burette into the copper solution heated to 65° to 85° C., at which temperature a constant compound ($5\,CuS + CuO$) is formed. The end of the reaction is recognised by the extinction of the blue colour of the solution. Zinc, antimony, arsenic, &c., are only precipitated after the copper, and are therefore not injurious. This assay is not quite so convenient as Parkes' method with potassium cyanide, and the test solution is much more variable. In the actual practice of copper works in this country Parkes' method (of which the Mansfield process described in the beginning is only an application) is that mostly employed.

COPPER ALLOYS.—Copper is probably capable of entering into combination with all the metallic elements severally, compounds being formed differing in character from their constituents. The contamination of copper with even very small quantities of some metals, such as zinc, iron, bismuth, and arsenic, materially alters its physical properties, rendering it a less perfect conductor of heat and electricity, and impairing its malleability and tenacity.

Potassium and sodium were formerly believed to increase the malleability of copper in a high degree. Dumas suggested the addition of cream of tartar to the fused metal as a means of producing it, and produced an alloy having the following composition:—

	Centesimally.
Copper,	99·12
Potassium,	0·38
Calcium,	0·33
Iron,	0·17
	100·00

Karsten states that copper thus treated only takes up 0·13 per cent. of potassium, and becomes less ductile; while according to Serullas copper does not alloy with cream of tartar when heated to redness.

Manganese forms many alloys with copper. They greatly resemble the bronzes; are very hard and sonorous, and melt very readily. The alloy containing 15 per cent. of manganese is grey, very hard and brittle, melts like bronze, may readily be cast, and does not alter much on keeping. Alloys containing less than 12 per cent. are ductile, and may be hammered into thin sheets. Manganese alloys are of a reddish colour, and become covered with a greenish tarnish when exposed to damp air.

With cobalt, copper forms ductile and malleable alloys, which melt at about the fusing point of copper.

An alloy of copper with aluminium, consisting of 10 parts of aluminium with 90 parts of copper, is known as aluminium bronze. It is a definite chemical compound, having the composition Cu_9Al. Being of a beautiful golden colour, capable of taking a high polish and little liable to oxidize, it is much used as a substitute for gold. Aluminium bronze is tough and hard, and at the same time very malleable. The affinity of aluminium and copper for each other is so great that plates of the two metals bound together, after having their surfaces well cleaned, can be welded by exposing them to a low red heat.

In 1858 a process was patented for making aluminium bronze by heating together a mixture of oxide of copper, aluminium, and carbon in the proper atomic proportions, the carbon being slightly in excess.

Iron is difficult to alloy with copper, but still compounds of this nature can be made.

The two metals alloy in all proportions. The copper is melted first, and the iron added by slow degrees. The colour of the alloy deepens until the metals are equal in quantity, after which each successive addition of iron renders the colour paler. An alloy containing 2 parts of copper with 1 of iron has very great tenacity; after this, addition of iron increases the hardness but diminishes the toughness. The presence of carbon prevents the combination of the metals. Mushet produced copper-iron alloys by fusing together the sulphides of the metals.

The principal part of the *black copper ore* already described is composed of copper and iron. A mixture of 100 parts of grey cast iron and 5 of copper yields an alloy of considerable hardness, which has been proposed as a material for anvils.

The presence of iron renders copper brittle and of a coarse grain; on the other hand, it was found by Faraday that even a trace of copper injures the quality of steel, and that in the proportion of 2 per cent. it renders it brittle; and Mushet states that it affects cast iron likewise.

The alloys of copper with cadmium, lead, antimony, and arsenic, have been hitherto of little use.

The most valuable alloys of copper are its combinations with zinc, tin, nickel, gold, and silver.

The term alloy was at one time exclusively applied to mixtures of metals with gold and silver, but in chemistry it now means the chemical combination of any two or more metals, or their solution in one another. The combinations of mercury are still known as *amalgams*. Alloys possess all the physical and chemical characteristics of metals; they have metallic lustre, are more or less ductile, malleable, elastic, and sonorous, and conduct heat and electricity. Though retaining these properties, the compound is often so modified in each of them that it does not resemble either of its constituents, and might consequently be regarded as a new metal, having distinctive characters peculiar to itself.

Many alloys consist of simple elements in definite or equivalent proportions, whilst others are produced from compound bodies; and often the components do not exist in the ratio of their chemical equivalents. Metals, in forming alloys, do not, however, combine indiscriminately with one another; the union is governed by the greater affinities which some of them manifest for each other. This all tends to prove that chemical combination is exercised, and that the alloys are not merely mechanical mixtures, but definite chemical compounds. Many of the alloys which have been hitherto examined corroborate this fact; and it is probable that peculiar properties belong to the combination when prepared in atomic proportions, such as is done in making the superior quality of brass. It is remarkable, also, that the native gold found in auriferous sands and rocks is alloyed with silver in the ratio of 1 equivalent of the latter to 4, 5, 6, 8, 10, &c., equivalents of the former; but the combinations never afford results indicative of the metals being united in fractional parts of an equivalent. Another evidence of the chemical combination subsisting is, that the compound melts at a lower temperature than the mean of the fusing points of its ingredients. An instance very remarkable in itself is the alloy of 8 parts of bismuth, 5 of lead, and 3 of tin; this compound fuses at the temperature of boiling water, although the the melting point deduced from the mean of its constituents is 514° Fahr. Thus iron, when alloyed with gold, enters into fusion at nearly the melting point of the latter metal, although when alone it is one of the most infusible elements. It is very probable that the true chemical alloy is often dissolved in excess of the free metal, and in this way evades recognition.

Again, as the melting point of the alloys differs from the mean of their constituents, so also, when the affinity between the metals is very great, the compound is generally denser than the mean, and *vice versâ*, as exemplified by the following compounds:—

Alloys, the density of which is greater than the mean of their constituents.	Alloys, the density of which is less than the mean of their constituents.
Gold and zinc.	Gold and silver.
Gold and tin.	Gold and iron.
Gold and bismuth.	Gold and lead.
Gold and antimony	Gold and copper.
Gold and cobalt.	Gold and iridium.
Silver and zinc.	Gold and nickel.
Silver and tin.	Silver and copper.
Silver and bismuth.	Iron and bismuth.
Silver and antimony.	Iron and antimony.
Copper and zinc.	Iron and lead.
Copper and tin.	Tin and lead.
Copper and palladium.	Tin and palladium.
Copper and bismuth.	Tin and antimony.
Lead and antimony.	Nickel and arsenic.
Platinum and molybdenum.	Zinc and antimony.
Palladium and bismuth.	

Crookewitt gives the specific gravities of alloys of copper with tin, zinc, and lead, as being modified as follows:—

	Sp. gr.		Sp. gr.
Cu,..............	8·794	Cu_2Zn_5,..........	7·939
Sn,..............	7·305	Cu_3Zn_2,..........	8·224
$CuSn$,............	8·072	Cu_2Zn,...........	8·392
Cu_2Sn,...........	8·512	Pb,..............	11·354
Cu_2Sn_5,..........	7·652	Cu_2Pb_3,..........	10·753
Zn,..............	6·860	$CuPb$,............	10·375

Hatchett found in his experiments on alloys of gold with silver, copper, lead, and antimony, of the standard proportion, that after long fusion and casting them in vertical ingots, the analysis of the several parts of these showed that the composition was not homogeneous, but that the top portion of the bar (corresponding to the metal which was in bottom of the crucible) contained more gold than the other parts. This is the case in every instance where there is a great difference in the gravity of the constituents of the alloy, unless great pains be taken to cause the metals to combine more perfectly; because, during the fusion, the chief portion of the heavy metals will assume a level in the crucible in the order of their respective densities, unless they are prevented from doing so by stirring with a porcelain rod. A partial separation of the metals takes place sometimes in the casting, even when all the attention possible may have been bestowed on the alloy during its formation; this is more especially the case if the casting be large and slow in cooling. The remedy for this is to fuse the ingots again, and after this the mixture will be found nearly homogeneous.

The tenacity of metals is generally increased by combining them together. Thus, an alloy of 12 parts of lead with 1 part of zinc has twice the tenacity of zinc.

Alloys oxidize more readily than their constituents do when separate. An alloy of lead and tin when heated to redness will continue to burn for some time, so rapidly does it absorb.

Alloys can only be formed by fusion; and since many of the metals oxidize with great readiness at the melting points, precautions have to be taken to stop this action, as otherwise the metals would not "wet" each other, their oxides forming a barrier.

For lead and tin resin or grease is commonly used to coat the surface; for tin and iron, sal ammoniac, &c. When more than three metals are to be combined it is found best to alloy them in pairs, and then to melt the pairs together. Brass, for instance, is improved for turning by the addition of 2 to 3 per cent. of lead. This, however, cannot be added directly, but has to be first run with the zinc and this alloy added to the melted copper.

Great art is required in the preparation of alloys, especially when they contain more than two metals; for it is not uncommon to observe two alloys of exactly the same composition differ very materially in properties, in consequence of a difference in the mode of preparation. This change often arises from the application of a higher temperature than usual, or from the order in which the fusion of the components is effected; to these points attention will be directed as the several compounds are described, and more especially in regard to the alloys of copper, which subject will now be resumed.

BRASS.—*Laiton*, *cuivre jaune*, French; *Messig*, German.—It would appear that no metallic compound was in more general use with the ancients than brass, it being apparently the best known to them. Tubal-cain is described as a worker in brass—copper (?) From the writings of Moses and Ezekiel also, the general use of brass is inferred, although it was evidently ranked in value far below silver and gold, as appears from the following passage, which also touches on other matters relating to ancient metallurgy:—*The house of Israel is to me become dross; all they are brass, and tin, and iron, and lead, in the midst of the furnace; they are even the dross of silver.*

Pliny says that a flourishing trade in brass was carried on in Rome shortly after the founding of that city, and that Numa, the immediate successor of Romulus, formed all the workers in this alloy into a kind of community. The author also gives a description of various alloys employed for casting, soldering, brazing, &c., and even mentions the proportions that were used. These alloys were modifications of bronze.

The first account of an alloy of copper and zinc was written by Aristotle; he states that the people who inhabited a country adjoining the Euxine Sea prepared their copper of a beautiful white colour, by mixing and cementing it with an earth found there, and not with tin, as was seemingly the custom. Strabo also alludes to the preparation of an alloy of copper by the Phrygians, from the calcination of certain earths found in the neighbourhood of Andêra; and other authors in the time of Augustus speak distinctly of *cadmia* (*i.e.*, calamine), and its property of converting copper into *aurichalcum*, under which title the zinc alloy was subsequently known.

The brass manufacture was introduced into England in Queen Elizabeth's reign—Daniel Houghsetter and Christopher Schutz, with a body of German workmen, being invited to this country to instruct workmen. A factory was opened in 1565. About a century later Momma and Demetrius opened a brass foundry at Esher, in Surrey, which ultimately failed. These were succeeded by the erection of the celebrated works of the energetic Prince Rupert. From this time the trade grew rapidly: brass cannon were cast at the Temple Water-mill Works at Hackney (still in existence), and foundries were opened at Bristol and Birmingham. The latter town is now the principal seat of the trade in this country. In 1800 Birmingham manufactured about 1000 tons of brass; in 1825 about 10,000 tons; in 1850, 20,000 tons; this rose in 1865 to 38,000 tons, and is at present about 50,000 tons.

Brass may be made by widely differing processes. The mode adopted commercially is to add zinc to melted copper; or to fill a crucible with alternate layers of zinc and copper, the whole being closed in with coke or charcoal. The old method of manufacture was to heat together a finely divided mixture of charcoal, copper, and calamine (native carbonate of zinc) in covered crucibles. Again, copper exposed at a red heat to zinc vapour is converted into brass. The brass wire used in "Lyons gold lace" is made by thus treating copper rods before drawing them out. Copper wire coated with brass may also be prepared by boiling it (after cleaning with nitric acid) in hydrochloric acid and cream of tartar with 1 part of zinc and 12 parts of mercury. Lastly, brass may be produced by electro deposition. (See Electro-Metallurgy.) From a solution of 1 lb. of cupric sulphate and 1 lb. of sulphuric acid in a gallon of water, the electric current deposits a brass which, though solid and compact, has a somewhat botryoidal surface. The addition of 1 oz. of zinc sulphate, according to Napier, renders the deposit tough, compact, and even. From a solution containing a greater proportion of sulphate of zinc the metal is deposited in tufts of needles. Ordinary brassing solutions show the same peculiarity in even a more marked degree, and this makes it impossible to produce a good deposit of more than 0·01 to 0·03 inch in thickness.

H. Walenn has pointed out a reason for this want of cohesion, and also a remedy for it. This form of deposit is, he believes, owing chiefly to a copious evolution of hydrogen taking place during its formation. By employing a solution containing both the oxides and the cyanides of the constituent metals, together with some neutral ammonium tartrate, this evolution of hydrogen may usually be avoided; or should it, nevertheless, take place to a slight extent, it may be entirely stopped by the addition of cupric ammonide. Such a solution yields brass of a uniform character, and the deposit, which may be obtained of any desired thickness, is tough, and has a compact even texture. As there is no evolution of hydrogen, no electric force is wasted, and perfect results may be obtained with a single Wollaston's or Smee's cell.

The whole of the compounds produced by the combination of copper and zinc in different proportions are included in the generic term *brass.* (The old English term was *latten.*) Many of these, however, present great differences in their physical appearance and properties. Alloys of copper and zinc may be made to assume every shade of colour, varying from the whiteness of the latter metal to the deep colour of gold, by a judicious admixture of the constituents. These varieties have been distinguished by fanciful specific names, as Prince Rupert's metal, pinchbeck, Mannheim gold, tutenag, tombac, similor, arcot, potin, &c. In the manufacture of common brass from calamine by the more ancient method, an impure alloy was obtained in the first stages, which is the arcot above mentioned; potin was formed in a similar way, when the finer quality of brass was made; both of these compounds contained a great many impurities.

The following table shows the general character of the principal alloys:—

ALLOYS OF COPPER AND ZINC.—R. MALLET, F.R.S.

		Composition per cent.	Spec. gravity.	Colour.	Fracture.	Cohesion per square inch in tons.
1	Cu	100·00	8·667			24·6
2	10 Cu + Zn	90·70 + 9·30	8·605	Reddish yellow.	Coarse crystalline.	12·1
3	9 Cu + Zn	89·80 + 10·20	8·607	Reddish yellow.	Fine crystalline.	11·5
4	8 Cu + Zn	88·60 + 11·40	8·633	Reddish yellow.	Fine crystalline.	12·8
5	7 Cu + Zn	87·30 + 12·70	8·587	Reddish yellow.	Fine crystalline.	13·2
6	6 Cu + Zn	85·40 + 14·60	8·591	Yellowish red.	Fine fibrous.	14·1
7	5 Cu + Zn	83·02 + 16·98	8·415	Yellowish red.	Fine crystalline.	13·7
8	4 Cu + Zn	79·65 + 20·35	8·448	Yellowish red.	Fine crystalline.	14·7
9	3 Cu + Zn	74·58 + 25·42	8·397	Pale yellow.	Fine crystalline.	13·1
10	2 Cu + Zn	66·18 + 33·82	8·299	Full yellow.	Fine crystalline.	12·5
11	Cu + Zn	49·47 + 50·53	8·230	Full yellow.	Coarse crystalline.	9·2
12	Cu + 2 Zn	32·85 + 67·15	8·283	Deep yellow.	Coarse crystalline.	19·3
13	8 Cu + 17 Zn	31·52 + 68·48	7·721	Silver-white.	Conchoidal.	2·1
14	8 Cu + 18 Zn	30·30 + 69·70	7·836	Silver-white.	Vitreo-conchoidal.	2·2
15	8 Cu + 19 Zn	29·17 + 70·83	8·019	Silver-grey.	Conchoidal.	0·7
16	8 Cu + 20 Zn	28·12 + 71·88	7·603	Ash-grey.	Vitreous.	3·2
17	8 Cu + 21 Zn	27·10 + 72·90	8·058	Silver-grey.	Conchoidal.	0·9
18	8 Cu + 22 Zn	26·24 + 73·76	7·882	Silver-grey.	Conchoidal.	0·8
19	8 Cu + 23 Zn	25·39 + 74·61	7·443	Ash-grey.	Fine crystalline.	5·9
20	Cu + 3 Zn	24·50 + 75·50	7·449	Ash-grey.	Fine crystalline.	3·1
21	Cu + 4 Zn	19·65 + 80·35	7·371	Ash-grey.	Fine crystalline.	1·9
22	Cu + 5 Zn	16·36 + 83·64	6·605	Very dark grey.	Fine crystalline.	1·8
23	Zn	100·00	6·895			15·2

No. 5 is not quite so good for rolling, hammering, or wire drawing as the common "red brass," which contains less copper in proportion to the zinc. No. 6 very much resembles "red brass," and is quite equal to it in most of its working qualities. No. 7 is well suited for rolling, hammering, and wire drawing; it is known as Bath metal or Prince's metal; the colour now begins to change into brass yellow. No. 8 is German or Dutch brass. No. 9 is brass for rolling. Its working qualities are precisely those of common brass. No. 10 contains 4 per cent more zinc and 4 per cent. less copper than ordinary English brass; it is well suited for rolling, hammering, and wire drawing. No. 11 is a German brass, it cannot be drawn into wire, and cracks under the rollers: is very flexible when strongly heated. It cannot be soldered, as it melts at the same temperature as the solder. No. 12 is a brass used in Germany by watchmakers. It corresponds in composition with "mosaic gold." Nos. 13 to 18 are very brittle; they are too hard to file or turn, but have a lustre when polished which is but little inferior to that of speculum metal. No. 19 breaks under the hammer. Nos. 20 to 22 are very brittle.

Prince Rupert's metal, pinchbeck, and Mannheim gold contain from 75 to 80 per cent., or more, of copper, and on account of their golden colour are employed to some extent in jewellery.

Tombac contains 84·5 per cent. copper and 15·5 per cent. zinc. It is the alloy used for the manufacture of "Dutch metal," an imitation of gold leaf. It can be beaten to a thickness of $\frac{1}{52900}$ of an inch. The tombac is first rolled into sheets and then beat out under a hammer worked by water or steam-power, which gives from 300 to 400 strokes per minute. At first twenty, then forty, and lastly eighty leaves are laid one on the other.

The composition of English brass is about 70 per cent. of copper and 30 per cent. zinc. Lavater found in common brass 70·29 per cent. copper, 29·26 per cent. zinc, 0·17 per cent. tin, 0·28 per cent. lead. Ure puts the composition of fine brass as 63·5 per cent. copper, 32·3 per cent. zinc; *i.e.*, Cu_2Zn.

In the manufacture of brass great care should be taken to free it from iron. This metal does not chemically combine with it at the temperature at which brass is made, and is usually found disseminated in small magnetic particles throughout the mass. Its occurrence happens when an impure calamine is employed in the manufacture, or when old brass containing it is the source of the copper. It renders the alloy prone to rust and tarnish when exposed to the air; making it also hard and dull, and considerably diminishing its tenacity and malleability.

Traces of tin and lead are occasionally detected in various kinds of brass, and sometimes these metals, instead of being injurious, are thought to be somewhat advantageous. Their presence arises from the employment of old brass which had been tinned over or soldered.

Lead is present when rosette copper is employed; its use is mostly confined to the Continental founders. This brass, although it is harder and more brittle than the ordinary kind, is more easily worked under the lathe; it may be welded together, and the junction is not easily broken; in addition, it can be cut with a chisel, sawn, and perforated with facility and exactness. The composition of this variety of brass is, according to DUMAS—

	Unknown.	Stolberg.	Plate Brass of Stolberg.	Plate Brass of Jemmapes.
Copper,	61·6	65·8	64·8	64 6
Zinc,	35·3	31·8	32 8	33·7
Lead,	2·9	2·2	2·0	1·5
Tin,	0·2	0·2	0·4	0 2
	100·0	100·0	100·0	100·0

The proportion of zinc in brass may be varied within certain limits, but when these are exceeded the results are not satisfactory. Practice has fixed the extremes of these between 30 and 38 per cent. of zinc, but as occasion requires the quantity may fall short or exceed this with advantage. Thus, when a rich alloy of considerable tenacity is required, the zinc is reduced to 25 per cent. or less, while with one of little resisting power 50 per cent. of zinc may be used; and should a hard and very brittle compound be desired, the zinc is raised to 60 per cent.

The alloy used as gilding metal should be easily melted and flow freely, should admit of being engraved and turned with facility, and of being gilt with the smallest possible quantity of gold. It will possess the latter quality if the grain of the brass is very fine and compact. All the alloys which are devoted to these uses are not, however, homogeneous in their composition, as the appended analysis of a few of them show—

	1.	2.	3.	4.	5.
Copper,	63·70	64·45	78·48	78·84	82·3
Zinc,	33·55	32·44	17·22	17·31	17 5
Tin,	2·50	0·25	2·87	0·96	0·2
Lead,	0·25	2·86	1·43	2·89	0·0
	100·00	100·00	100·00	100·00	100·00

The densities of the first and second alloy here mentioned are respectively 8·395 and 8·542. These are the best adapted for the purposes of the jeweller. In the other three samples the amount of copper is much larger, although intended for the same purpose, and very often it is increased to 90 and 95 per cent., in which case it is analogous to chrysocolla. The product is then called gilding metal, while the others are termed Bath metal, pinchbeck, Mannheim gold, and "similor." Lead and tin do not affect the quality of the brass for certain works; but where it is requisite that the brass should be very tenacious the least quantity of these metals will prove detrimental. Thus appreciable amounts of lead or tin are highly injurious in brass of which it is intended to make wire; nevertheless this kind of alloy always contains traces of other metals, as the following analyses of wire-brass show:—

	Per Cent.	Per Cent.
Copper,	66·2	67·0
Zinc,	33·0	32·0
Tin,	0·8	—
Lead,		0·5
Antimony,	—	0 5
	100·0	100·0

Another variety of brass, which is employed in operations where it is requisite that the metal should work well under the hammer, is composed of copper and zinc in the following proportions:—

Copper,	70·1
Zinc,	29·9
	100·0

Metal for the manufacture of pieces of machinery and locomotives has the composition—

Copper,	74·5
Zinc,	25·0
Lead,	0·5
	100·0

The fracture of this alloy is of a fine yellow colour; it is not so malleable as those in which the quantity of zinc is less. Generally, as the percentage of zinc increases the malleability is decreased; hence, for working brass, the best varieties are obtained when the zinc constitutes from 20 to 33 per cent. of the whole.

BRASS MANUFACTURE.—Brass founders in place of percentage composition speak of the amount of zinc only, it being understood that the ratio is to the pound of copper. Thus they would say to make copper cast well alloy one-eight to half an ounce of zinc with each pound of metal. The manner in which this is sometimes done is by fusing four ounces or less of brass with the above quantity of metal. The proportion reckoned upon in making "gilding metal" is one to one ounce and a quarter of zinc; and, like the foregoing, this alloy is not made by the union of its components directly, but by the fusion of a definite proportion of brass and copper. In red sheet brass the pound of copper is proportioned to three ounces of the secondary metal.

Mannheim gold, pinchbeck, Bath metal, and several other alloys, all of which possess more or less of a golden colour, are formed with three or four ounces of zinc to the pound. The true brass, from which all the other varieties are called, is formed of two parts of copper and one part of zinc; and metal which bears soldering well, such as Bristol brass, contains a smaller quantity of the secondary metal.

The following table exhibits the proportion in which these are employed, namely:—

	Bristol brass.	Muntz metal.	Muntz sheathing.	Spelter solder.	Pale yellow metal.	Mosaic gold.
	oz.	oz.	oz.	oz.	oz.	oz
Copper,..	16	16	16	16	16	16
Zinc,....	6	10⅔	9 to 16	12 to 16	12	16½ to 17

It is always necessary to employ somewhat more zinc than is here mentioned, in order to cover the quantity which is volatilized by the great heat usually resulting from the union of the two metals; unless this precaution be taken, or provision be made for preventing the volatilization of the zinc, the resulting alloy will often be quite different from what was intended.

Long before the isolation of zinc, and when, consequently, its combination with copper could not be effected directly as is now generally done in brass-foundries, the ancients were well acquainted with brass and the method of preparing it. The course they followed, and which was in practice in this country thirty years back, was to fuse the copper with an ore of zinc and charcoal, by which treatment the zinc was reduced and combined with the copper without becoming known as a distinct body. Calamine, blende, and other compounds of zinc were commonly used in the manufacture, but it was customary for these to undergo a calcination before they were fused with the copper and charcoal. This method has now so completely died out that it is doubtful if a single calamine furnace remains in England.

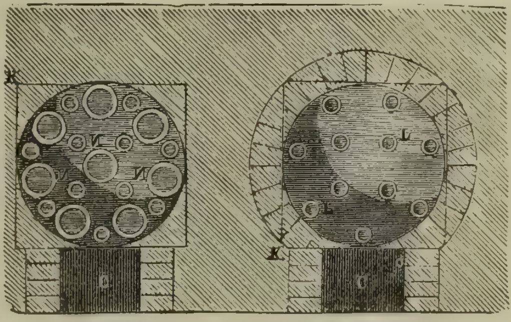
The materials which the founder employed in manufacturing brass in this way were bean copper or rosettes (from which the silver had been abstracted by eliquation with lead), calcined calamine, blende, and charcoal, the proportion of the latter two being regulated according as it was intended to produce red or yellow copper.

In this method it was of great importance that the zinc ore should be free from any sulphurous compounds, and also from silicate of zinc; the former was injurious, inasmuch as it rendered the alloy brittle and of a bad colour, and the latter was not reduced in the crucible in the ordinary way, although, by the aid of lime or carbonate of lime, it might be made to yield its zinc to the copper, while the silica flowed off in combination with the earthy base. Another matter of importance was, that the material should be well calcined, otherwise the reduction of the zinc would be more difficult than if roasting was properly executed. Frequently this operation was performed by placing alternate layers of calamine and coal or charcoal upon one another in the form of a mound, the base being formed of large billets of wood. The mass was ignited at the top.

After calcination the roasted mineral was prepared for the operation of smelting and uniting it with the copper, by grinding it under head-stones, and subsequently sifting to remove the grosser particles. With rosette, grain, or bean shot copper the alloy thus made was seldom richer in zinc than 27 or 28 per cent.; and before it was fit for the market it had to be melted with a fresh quantity of the ore in order to bring it to the marketable standard. Sometimes old brass and other cupreous matters were used in founding the metal in this way; in such cases impurities in the shape of lead, iron, tin, were incorporated. This has to be borne in mind in analyzing old brasses.

Two distinct operations were followed in preparing the brass by this method; the first, to form the alloy just mentioned, generally known as *arcot*, and the second, to render this marketable by combining it with a further proportion of zinc. The fusion was effected in large crucibles or pots, placed in a circular hearth, as in the case of bismuth.

Fig. 1.



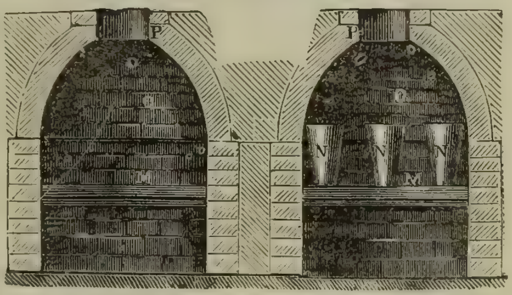


Fig 2.

Figs. 1 and 2 represent the furnaces used in the brass foundry, Fig. 1 being a plan and Fig. 2 a section of the oven. K K are square cast plates which form the base of the oven. These plates are perforated in eleven places, as seen at L L, for the purpose of carrying air into the kiln, and allowing the cinders and ashes from the fuel to fall into the pit beneath. M M, the area or floor of kiln, made of refractory clay. N N are the pots for fusing the material, of which eight are in each kiln; and O O, the arches over them, which are cast in moulds, and are composed of the same material as that of which the pots are made, only less care is bestowed upon them than upon the latter. When finished the mould, which consisted of seven or eight parts, was sundered. The arch was some inches flat at the base, that it might press strongly and securely. P P P represent the top casting, which forms the mouth of the kiln, opening into the cover, which rests upon the arch.

The height of the kilns was equal to their breadth, which was about 1½ foot. They were each capable of holding six or eight pots, the capacity of which was such as to contain collectively from 1 to 1½ cwt. of brass. The fuel employed was generally coke or coal in pieces of moderate size, so as not to intercept the draught. The furnace and pots being heated, the attendant took one of the latter and filled it to the brim with the mixture of calamine and charcoal, and then forced into it the necessary quantity of the rosette or grain copper, or arcot, by a few blows of a mallet or hammer, and after this was done, sprinkled a few handfuls of the charcoal mixture on the surface. The crucible was then deposited in the fire, and others charged in the same way in succession, till the kiln was full. Pieces of fuel were then added in such quantities and in such a manner that the pots were covered, but not overloaded with them. The furnace was then closed and left undisturbed for six or seven hours, the temperature being kept up for the whole time. At the end of this period the contents of the pots were at a white heat; the fire was again revived and kept in active combustion for a short time, until the fumes of the volatilizing zinc, which are significant of the reduction and fusion of the metal, appeared. As soon as this happened the fire was checked, in order that the copper might not melt too rapidly, and thus prevent the prolonged exposure to the fumes of the melted zinc, which exposure is essential to insure a good combination. About three or four hours served to effect this process. When the combination was complete, the pots were removed from the kiln, and the dross or portion of oxide on the surface skimmed off and the casting made.

At Holywell, in North Wales, the calamine was found mixed with a large quantity of lead ore, which was removed by picking, grinding, and washing. The calcination was then performed in the ordinary way, and with the usual precautions of stirring, &c., in a furnace the bed of which was almost horizontal. After the roasting the material was reduced to powder in a mill, and at the same time mixed with about one-fourth of its weight of charcoal. The crucibles or pots, made of refractory clay, were filled with this mixture, and the proper amount of red or grain copper, and the covers luted on with a material composed of refractory clay and horse dung. The proportion of the materials was for the most part—

40 lbs. of grain copper, and
60 " of calamine and charcoal mixture;

from which 60 lbs. of brass, containing 33 per cent. of zinc, was obtained. The period of reduction and combination was about twenty-four hours.

In fusing the mixtures above described no scoriæ are produced, all the silica being united with substances which do not enter into fusion at the temperature of the kiln or pot. Hence the great loss which resulted from the use of zinc compounds which contain much zinc silicate, for besides what was liable to be lost by the oxidation of some of the reduced metal, all this passed away unchanged.

The manufacture of brass from calamine was exceedingly laborious, and the expenditure in fuel was such that more than twice the quantity was used than is requisite now that the alloy is made by fusing the metals together. Another advantage in the latter mode is that more than double as much as could be procured by the old method can be formed in twenty-four hours with far less labour. The principal difficulty to be contended with in the present mode of working is the rapidity with which the zinc is deprived of its property of alloying with the metal, owing to its affinity for oxygen. For this reason, when the proportions of an alloy as determined by chemical analysis are synthetically employed to form a similar article, the result is generally a failure; either more of the metal prone to oxidize must be employed, so as by this excess to make up for that which becomes lost, or some means must be adopted to exclude the "foul" air, as it is termed in the language of the workman. Covering the alloy with suitable fluxes renders great service in this respect, not only in preventing the oxidation, but, as a consequence of the first, excluding this oxide from afterwards mixing with the metal and injuring its quality. Salt cake is commonly used for this purpose. The loss of zinc would be much greater were it not for the strong affinity which exists between it and copper. This has been taken advantage of in a process for coating copper with brass, in which sheet copper at a high temperature is simply exposed to fumes of zinc.

The late Earl of Rosse recommended a furnace or kiln deeper than usual, and the covering of the metal at all times with a layer of powdered charcoal 2 inches thick. When these conditions are fulfilled it is affirmed that only about the 180th part of the zinc is lost. Holtzapffel found that under ordinary circumstances the loss is at the least a thirtieth of the whole alloy. He fused 24 lbs. of copper, and determined the loss which was thus sustained. An equal weight of the same material was afterwards fused; 12 lbs. of zinc in plates of about three-fourths of an inch thick were then broken up into convenient-sized fragments, which were added one by one at regular intervals to the fused copper till the whole was introduced. When this happened the surface of the liquid compound metal was covered with glass and left to the action of the heat for fifteen minutes, or till such time as the fumes of zinc gave indications that the contents of the pot were in perfect fusion. Having removed the pot from the fire, stirred its contents for a short time, it was cast, and the result of two experiments thus conducted showed that instead of obtaining 33⅓ per cent. of zinc, the proportion found was 31¼, or 7¼ ounces of zinc instead of 8 to the pound. Further, on remelting quantities of this alloy it continued to lose zinc, till after the sixth operation the alloyed metal was reduced to 4⅝ ozs. to the pound.

The direct preparation of brass by the combination of the two metals is in ordinary brass foundries brought about by fusing first the copper and then the zinc in crucibles, or (a much more wasteful mode of working) in reverberatory furnaces.

The crucibles employed are either of burned fireclay, Hessian, Berlin, or Stourbridge, or of a mixture of 1 part of fireclay with 2 parts of blacklead. These latter, termed blue pots, are then carefully dried in a kiln. They are found to stand sudden changes of temperature without cracking, and are non-porous at the highest degree of heat they are likely to be subjected to: hence they have almost entirely superseded the burnt fireclay crucibles.

In the early days of brass founding the zinc was melted first, and pieces of copper gradually added, the heat of the furnace being raised by degrees as the fusing point of the alloy became higher.

The modern method of working reverses the proceeding; the copper is melted first, and the zinc, first having been made hot, is added by small instalments until the fusion is complete.

After the furnace is well alight, the crucibles are placed on the hearth bottom upwards and heated to redness; they are then set the right way, and the charge of copper introduced, to prevent oxidation a few pieces of charcoal being placed in the mouth of each crucible. The heat of the furnace is then gradually raised until the whole of the copper is fused. The zinc in small pieces has been in the meantime getting hot at the mouth of the furnace; it is now seized piece by piece with crucible tongs and held beneath the surface of the melted copper until dissolved. When the whole of the charge is in the crucibles and fused, it is well stirred with a hot brass or iron stirrer, and then decanted into the moulds or into a casting vessel, if the contents of several crucibles are required for a large casting. The fuel should be good coke.

The English furnaces are either square or round. The square furnace is built up exclusively of cast-iron plates, bolted together by strong tie-rods; within this iron casing 18-inch brickwork forms a chamber to hold a single crucible. The round furnace is a cast or wrought-iron cylinder, 2 feet in diameter by 4 feet long, lined with fire-clay, so that its internal width is reduced to about 1 foot. The bottom of each furnace is formed of ordinary furnace bars, the air being admitted, as in the foreign furnaces, through a sunken ash-pit which communicates with the outside of the building. The mouth of the furnace is closed by a loose cast-iron cover, which can be luted down.

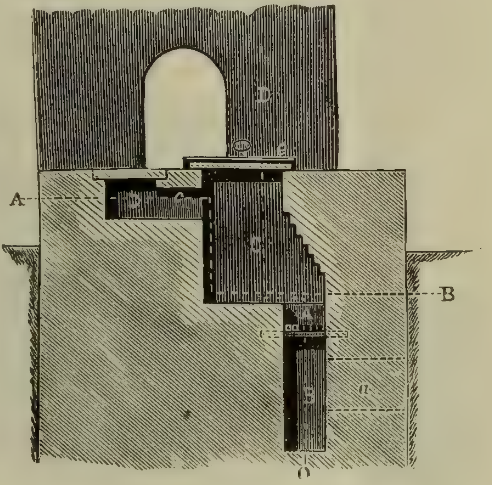
A form of brass furnace in use in Germany, to be heated with coal, has an oval chamber with a flattened ceiling. The sole of the furnace is within this chamber, and communicates with it by ray-like disposed through its walls.

The furnace bottom with its connecting walls thus forms a star-shaped chamber with an opening in the middle, from which the ray-like channels proceed to the periphery. The crucibles, of any desired circumference, stand upon this hearth, and beneath it is the fire grate for the coal, the flame from which traverses first the oval chamber and then through the numerous openings the hearth itself. The crucibles are introduced through an opening in the crown of the furnace, which is afterwards closed by a well fitting iron plate provided with a handle, by which it can be lifted up when desired.

Blast furnaces are likewise used, some of which hold one, others two crucibles. The crucibles stand either on the fire grate itself, or upon a flat hearth just above the arch of the fire grate.

Figs. 3 and 4 show an oven with a separate fire, much used in Belgium. A is the fire grate, B the ash-pit. This has a wide canal, *a*, cut through it for the admission of air to the fire. C is the melting chamber; it will be observed that the hearth is raised somewhat above the level of the fire bars. The flues, *c*, lead into the chamber D, which is furnished with a damper at *d* for the regulation of the draught. The products of combustion are finally carried off by the flue, E, into the chimney shaft. A portable iron cover, *e*, is over the opening; through which first the crucibles, and afterwards the copper and zinc, are put into the furnace.

Fig. 3.



In large foundries the melting ovens are now very generally heated by Siemens' regenerative furnace. (See Fuel.)

When it is desired to cast brass into ingots, moulds are employed which are sometimes made of blocks of granite bound together with iron, and having the intervening space regulated by bars of iron, the thickness of which corresponds to the intended casting. Usually, however, the moulds are of cast iron. They must be heated before the molten brass is poured into them.

Previous to tapping the furnace, samples are taken out, cast into ingots, and passed through the rolls whilst still hot, and afterwards broken across. The fracture which presents itself should be close and have a very fine grain; if the testing is unsatisfactory more and more zinc is added, until the test ingot shows the desired quality.

Brass subject to tension sometimes undergoes a remarkable molecular change; loses its tenacity, and in a short time becomes almost as brittle as glass. The circumstances under which this change takes place have never been investigated.

Brass which contains more than 50 per cent. of copper behaves like copper in the voltaic cell, and does not precipitate the salts of copper; while that which has an excess of zinc decomposes copper salts and becomes converted into pure copper: it dissolves completely in acids which do not attack copper alone.

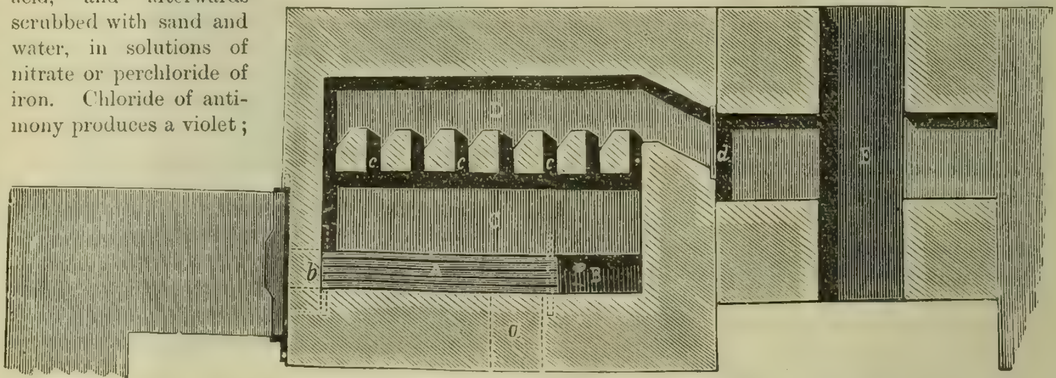
Brass expands $\frac{1}{533}$th of its length on being heated, and when hot can be rolled or beaten to any required thinness.

Bronzing.—To prevent continuous oxidation of brass it is the custom to induce a surface oxidation, which shall form a protecting coating over the rest of the metal. Various shades of colour are obtained by varying the oxidizing agents and the degree of oxidation. Brass left in wet sand becomes brown, but this colour is given much more expeditiously by dipping brass which has been well cleansed by pickling in dilute nitric acid, and afterwards scrubbed with sand and water, in solutions of nitrate or perchloride of iron. Chloride of antimony produces a violet; arsenious acid grey (by the deposition of a film of the metal); black is obtained with bichloride of platinum; green by dipping in a solution of iron and arsenic in muriatic acid. Almost any colour may be obtained by making a mixture of 2 oz. of pernitrate of iron and 2 oz. of hyposulphite of soda in 1 pint of water, and immersing the brass in the liquor until the required shade makes its appearance, then wash well with water, dry and brush. One part of perchloride of iron to 2 parts of water mixed together, and the brass immersed in the liquid, gives a pale or deep olive green, according to the time of immersion. If nitric acid is saturated with copper, and the brass dipped in the liquid and heated, it assumes a dark green.

Black Bronze for philosophical instruments.—Dip the brass in aquafortis, rinse the acid off with clean water, and place it in the following mixture until it turns black:—Hydrochloric acid, 12 lbs.; sulphate of iron, 1 lb.; pure white arsenic, 1 lb. It is then taken out, rinsed in water, dried in sawdust, polished with blacklead, and coated with green lacquer.

Lacquering.—The brass is made as clean and bright as possible, either by polishing or pickling: in the latter case it is dried in hot sawdust. After which, for dead brass, it is dipped for an instant in a solution of 1 part of nitric acid with 4 of water; if bright brass is desired, it is dipped in strong commercial nitric acid; and in any case it is finally, to preserve the colour until lacquered, well washed in water containing argol.

Fig. 4.



The articles to be lacquered are heated on a hot plate, and varnished with one of the following lacquers:—

Pale Lacquer.—1 gallon of methylated spirit, 5 oz. of shellac, 4 oz. of gum sandarach, and 1 oz. of gum elemi; mix in a tin flask, and expose to a gentle heat for a day or two, then strain off and add half a gallon of spirit to the sediment and heat as before.

Green Lacquer.—Add to the pale lacquer, when mixing, 6 oz. of turmeric and 1 oz. of gum gamboge.

High-coloured Lacquer.—2 quarts of methylated spirits, 2½ oz. of shellac, 2 oz. gum sandarach, ½ oz. gum elemi; mix and keep gently warmed for two or three days; strain colour with dragon's blood to taste, and thin with 1 quart spirits of wine.

Common Lacquer.—1. Seed-lac, dragon's blood, gamboge, of each 4 oz.; saffron, 1 oz.; spirits of wine, 10 pints. 2. Shellac in spirits of wine in the proportion of 1 oz. to the pint. Colour with red sanders, dragon's blood, or annotto, for red-tinged lacquers, or with turmeric, saffron, sandarach, or gamboge, for yellow lacquers.

The brass must not be heated beyond the boiling point of the varnish, and after lacquering must be returned to the hot plate until the lacquer has set.

Muntz's Metal.—This kind of brass is generally composed of 40 parts of zinc with 60 of copper. The metal after being properly melted is cast into ingots, heated to a red heat, and rolled into sheets. The sheets are pickled with dilute sulphuric acid to free them from adhering scale, and afterwards washed in water. It is of importance that the heat be maintained at nearly a red heat during the rolling, as otherwise the metal frays and cracks. In 1846 a patent was taken out by Muntz for an alloy, which consists of 56 per cent. of copper, 43·25 zinc, and 3·75 lead. The alloy is cast into ingots, which are to be rolled at a red heat.

MUNTZ's metal, or "Patent Yellow-metal Sheathing," as it is called, has almost entirely superseded copper sheathing for merchant ships. It is said that by the exposure to sea water of this brass the zinc slowly and uniformly corrodes over the entire surface, and while so doing prevents barnacles, &c., from attaching themselves. "FARADAY," says Dr. PERCY, "informed me, that in a specimen of sheathing formed of the alloy in question, which had been long exposed to the action of sea water, he found no zinc remaining."

MUNTZ's metal is almost always cast in reverberatory furnaces, the zinc being added to the melted copper; when the fusion is complete the furnace is tapped, and the alloy runs off into a fire-clay receptacle, from whence it is ladled into iron ingot moulds of a suitable size for the rolling-mill. These moulds must be oiled and lightly dusted with charcoal.

GERMAN SILVER.—*British plate; cuivre blanc, maillechort*, French; *argentan, neusilber, weisskupfer*, German.—This is an alloy of nickel, copper, and zinc, which owes its peculiarity more to the first than to the other metals; still, as the copper is the main ingredient, a brief account of it will be given here as one of the copper alloys. It has long been known to the Chinese under the name *pakfong*, or white metal. It was first introduced into this country from Germany, as its name implies, where it had been prepared by smelting an ore found at Hilburghausen, near Suhl, in Henneberg. KEFERSTEIN found this alloy contained—

	Per Cent.
Copper,	40·4
Nickel,	31·6
Zinc,	25·4
Tin,	2·6
	100 0

The Chinese pakfong always contains 2 or 3 per cent. of iron, and this is said to give it a brighter colour, and to render the alloy more compact; but then it confers hardness and brittleness also, and these militate against its use in many cases. As the nickel necessary to prepare German silver is much rarer than the other constituents, metallurgists have considerably diminished its proportion, substituting zinc; in doing so the brightness of the alloy is not much impaired, so long as the ratio remains within a certain limit, but once this is passed the compound presents a fair appearance for a very short time, and then assumes the hue of pale brass. The following table represents the composition of a number of these alloys :—

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Copper,	43·8	40·4	53·4	50·0	65·4	60·0	57·0	59·2	55·0	51·6	45·7
Nickel,	15·6	31·6	17·5	18·7	16·8	20·0	20·0	14·8	20·6	25·8	34·3
Zinc,	40·6	25·4	29·1	31·3	13·4	20·0	20·0	26·0	24·4	22·6	20·0
Iron,	—	2·6	—	—	3·4	—	Lead, 3·0	—	—	—	—
	100·0	100 0	100·0	100·0	100 0	100·0	100·0	100·0	100·0	100·0	100·0

Numbers 1 and 2 are the analyses of samples of Chinese pakfong, the latter being a very superior quality in point of colour and structure, so that it can be very highly polished. 3 and 4 represent the composition of alloys prepared by FRICK. They resemble very much a silver alloy containing about 18 carats to the ounce. They are hard, but very tough and ductile, becoming soft by immersing into cold water, and their specific gravity at 67° Fahr. is 8·556. Number 5 is *maillechort* made at Paris, having a specific gravity of 7·18. It may be rolled out into very thin plates and polished to a high degree. It loses about 12 per cent. when heated, and this loss renders it much whiter than before. Numbers 6 and 7 are recommended by GERSDORFF of Vienna, the first for forks and such like articles, and the second for such objects as require soldering. The commonest German silver is, according to TOPPING, represented by number 8. It should be used only for wire-drawing and other common purposes. If the quantity of nickel be reduced below this, the alloy will be little better than pale brass, and will tarnish rapidly. Number 9 is a very beautiful compound, but little inferior in appearance to standard silver. It is often preferred to the more costly compounds. The richest alloy which can be made, without injuring the mechanical properties of the metal, is number 11. It is a very beautiful compound, but more difficultly prepared than the preceding, owing to its requiring a high temperature for its fusion.

An alloy called *tutenag*, and composed of 45·7 of copper, 17·4 of nickel, and 36·9 of zinc, is very serviceable, especially for casting. It is in frequent use among the Chinese. It is very fusible, but hard, and not easily rolled, and in colour resembles very much the alloy *electrum*, the analysis of which is given in number 9 of the foregoing table.

Much nickel silver is manufactured at Sheffield; the proportions of the ingredients are as follows :—

	Common.	White.	Electrum.	Infusible.	Tutenag.
Copper,	8	8	8	8	8
Zinc.	3·5	3·5	3·5	3·5	6·5
Nickel,	2	2	4	6	3

H. WATTS gives the composition of nickel silver for spoons and forks as :—2 parts copper, 1 nickel, 1 zinc; for knife and fork handles :—5 parts copper, 2 nickel, 2 zinc. The addition of 3 per cent. of lead to the first of these mixtures, or 2 per cent. to the second, yields an alloy adapted for casting.

A small quantity of iron hardens considerably these alloys, and likewise gives a bright colour; but it renders the metal more difficult to work.

German silver is prepared by melting together the constituents of the alloy; the work is performed in pots or crucibles in the same way as in the manufacture of brass, and much of the zinc passes off by volatilization and oxidation. By care, however, this loss may be reduced to some extent; still a large quantity escapes, which must be made up in the alloy by taking a larger proportion of zinc. It is the usual custom to have the metals arranged in alternate layers in the crucible, the lowermost and topmost being copper; charcoal powder, dust, or powdered glass are strewn upon the surface. Or it may be made by melting the metals consecutively: in this case the copper is fused first, then the nickel is added, and when the whole is melted the zinc put into the crucible piece by piece, and held beneath the surface until absorbed. When the metals enter into fusion, it is necessary that the contents of the pot should be stirred with a porcelain rod, in order that the compound may be homogeneous.

Nickel silver has a crystalline structure when solidified from fusion. It must therefore be heated to dull redness and cooled again completely before it is rolled or hammered, but when once the crystalline structure has been destroyed the alloy may be worked like brass.

Chinese nickel silver may be heated to dull redness without losing its malleability, but if the temperature is carried beyond this point it flies to pieces with a very slight blow.

BRONZE.—This alloy is composed of copper and tin; it is the compound which was known to the ancients under the name of *brass*, and of which they made all their implements of war and domestic economy before iron came into general use.

The principal uses of bronze are in the making of the baser currency, in statuary, cannon and bell founding, in casting medals, &c. The rage for statues of this metal was very great in the time of Alexander the Great. Castings in bronze had long before been made; but the celebrated artist Lysippus, by his discovery of the means of moulding, afforded such facilities for the art that so many bronze statues were erected that Pliny called them the *mob of Alexander*. Huge colossi were also raised and multiplied, and it is related that Mutianus, the Roman consul, found 3000 bronze statues at Athens, the same number at Rhodes, and as many at Olympia and Delphi.

Mallet gives the characteristics of various alloys of copper and tin in the following table:—

Copper.	Specific Gravity.	Colour.	Fracture.	Tenacity.	Order of Malleability.	Order of Hardness.	Order of Fusibility.
Per Cent.							
100	8·607	..	..	24·6	1	10	16
84·29	8·561	Reddish yellow,	Fine grain,........	16·1	2	8	15
82·81	8·462	“	“	15·3	3	5	14
81·10	8·459	“	“	17·7	4	4	13
78·97	8·728	“	Vitreous conchoidal,	13·6	5	3	12
76·29	8·750	Pale red,......	“	9·7	Brittle,..	2	11
72·80	8·575	“	“	4·9	“ ..	1	10
68·21	8·400	Ash grey,......	“	0·7	Friable,.	6	9
61·69	8·539	Dark grey,....	Laminar,..........	0·5	“ .	7	8
51·75	8·416	Greyish white,.	Vitreous conchoidal,	1·7	Brittle,..	9	7
34·92	8·056	Whiter,.	Laminar,..........	1·4	“ ..	11	6
21·15	7·387	Still whiter,....	Vitreous,..........	3·9	“ ..	12	5
15·17	7·447		“	3·1	8 Tough,	13	4
11·82	7·472		Laminar,..........	3·0	6 “	14	3
9·68	7·442		Earthy,............	2·5	7	15	2

Bronze is more fusible than copper. Its density is greater than the mean of its constituents; but this is subject to some little derangement, owing to the vesicular structure which the ingot or casting assumes at the point of solidification, by which its bulk is increased, and of course the real gravity of the metal reduced. Hence, to ascertain the true specific gravity of bronze, portions of the ingot should be cut off and reduced to fine powder, and weighed in this state; and the extent of the preceding error might be determined by ascertaining the apparent density in the bulk previous to the reduction to powder, and comparing it with the secondary results. The following table of a few of these alloys shows their calculated specific gravity, and the difference between these and the mean as found in practical working:—

Alloy.				
Copper.	Tin.	Observed density.	Calculated density.	Difference.
96·2	3·8	8·79	8·74	0·05
94·4	5·6	8·78	8·71	0·07
92·6	7·4	8·76	8·68	0·08
91·0	9·0	8·76	8·66	0·10
89·3	10·7	8·80	8·63	0·17
87·7	12·3	8·81	8·61	0·20
86·2	13·8	8·87	8·60	0·27
75·0	25·0	8·83	8·43	0·40
50·0	50·0	8·79	8·05	0·74

The alloys in most general use are bell-metal, composed of about 78 parts of copper to 22 of tin; gun metal, which consists of 90 parts of copper and 10 of tin; and statuary bronze, which commonly contains lead and zinc as well as tin.

A peculiar behaviour of bronze when cast in sand moulds, more especially if they be large, is that shortly after casting a jet of liquid metal issues from the interior, either at the sides or at the upper surface of the metal. This has been accounted for by supposing that the first portion of the alloy which comes in contact with the walls of the mould condenses, and in so doing contracts to some extent, and by this means displaces the more expanded molten matter inside; and if the pressure of the metal from above is considerable, so as to prevent the ascent, it will exude laterally; but when the weight thus bearing upon it is not very great, it forms an upward current. It has been found that the metal thus thrown out is much richer in tin than the remainder of the alloy, and that in these parts also great variations are often detected, as the annexed table, from the experiments of Dussaussoi, who examined two castings with the following results:—

		At the surface, and within six inches of the base.	At the centre, and within six inches of the base.	At the top surface.
Ingot 3 inches square, and 13 in height, weighing 40 lbs.,	Copper,	89 09	90 63	90 54
	Tin,	11·91	9·46	9·46
		100·00	100·00	100·00
An ingot of the same dimensions moulded in sand,	Copper,	90·0	90·9	83·6
	Tin,	10·0	9·1	16·4
		100·0	100·0	100 0

Bronze containing about 85 per cent. of copper and the remainder of tin is somewhat malleable. This property can be communicated to a much greater extent by tempering the metal like steel, but with opposite effects. Even alloys composed of proportions different from the foregoing may, by a similar treatment, be made to work under the hammer. The tempering in this case lessens the density of the metal, as also the hardness; it affects the malleability and flexibility, and sometimes renders it more tenacious, besides giving a duller tone to the sound of the alloy.

Many articles require in their preparation that the bronze should partake of some of these properties, and therefore objects after being cast are often slightly tempered, that they may be made more easy to work under the hammer, the lathe, or the press, and when thus finished the hardness is recommunicated by heating them.

According to Dussaussoi, the alloy which best comports itself under this treatment is composed of 8 equivalents of copper and 1 of tin. Bronze of this composition, he states, always increases in tenacity when the ingots or objects are of some thickness, whereas, with the most part of the others, the contrary is the case. The annexed table shows the results of some experiments which he made upon his subject:—

		Composition of the alloy, centesimally.				
Copper,		95	90	85	80	75
Tin,		5	10	15	20	25
		100	100	100	100	100
Density before tempering,		7·92	8·08	8·46	8·67	8·57
Density after tempering,		7 89	8·00	8·35	8·52	8·31
Hardness before tempering,		100	100	100	100	100
Hardness after tempering,		99	98	96	92	91
Sample ¾ths of a line in thicknesss,	before tempering, tenacity,	80	66	48	50	70
	after tempering, tenacity,	100	100	100	100	100
Sample of eight lines in thickness,	before tempering, tenacity,	100	100	80	80	100
	after tempering, tenacity,	75	78	100	100	35

Other circumstances tend to modify the quality of bronze considerably, the principal of which is the liability to alter in composition during the melting, by the oxidation of the tin. Many large castings manifest this imperfection to a considerable extent, more especially if the metal required many fusions before the objects were finished. That of Desaix in the Place Dauphiné, and the column in the Place Vendome, are noted specimens of most defective workmanship, owing to the want of knowledge in regard to the cause of the defect already mentioned.

On analyzing, separately, specimens taken from the bas-reliefs of the pedestal of the latter column, from the shaft and from the capital, it was found that the first contained, centesimally, 6 of tin and 94 of copper, the second contained much less tin than the first, and in the third, the tin was found as low as 0·21. Hence it will be seen that the founder, instead of maintaining the alloy at its average composition, allowed the copper to be gradually refined, the other metal being thrown off as oxide. If the alloy be exposed to the air during the fusion, both the metals constituting it will be oxidized, but in very unequal proportions; thus, in an alloy composed of 91 parts of copper and 9 of tin, for every part of the latter which is thrown off, there are two or three of the former, but it is evident that ultimately the mass would be deprived of all the tin. The numbers annexed show the extent of the oxidation, and the variation in gravity which took place in the sample studied. The alloy was ordnance metal, cast in sand, and contained 90 parts of copper and 10 of tin.

Number of fusions.	Weight of ingot in ounces.	Loss per cent.	Specific gravity.	Composition.	
				Copper.	Tin.
1	268	1·2	8·565	90·4	9·6
2	236	1·6	8·460	90·7	9·3
3	204	2·1	8·386	91·7	8·3
4	172	2·5	8·478	92·8	7·2
5	140	2·6	8·529	93·7	6·3
6	104	3·0	8·500	95·0	5·0

In addition to the loss suffered by the oxidation, another of a more serious nature attends it, namely, the incorporation of some protoxide of the metals in the alloy, which renders it brittle, and not calculated to wear well. It is, however, easily remedied, and requires only the fusion of six or seven ingots, with the requisite quantity of tin, together with some charcoal, and, if found necessary, poling the bath as in the refining of copper. All the oxides are thus reduced, and the alloy acquires a fine grain, and no bubbles appear in any part.

Some manufacturers introduce a small amount of iron into bronze in the founding; but experience has proved that this should only be employed in brass which is destined for small objects, as it gives to them hardness and tenacity, which are unnecessary in large castings. The quantity used should never exceed about 1 and 1½ per cent. of iron, and it should be incorporated in the form of white or tinned sheet-iron. Ferruginous alloy is always less fusible than ordinary bronze, and on this account is less disposed to form cavities in the mass when cast in sand moulds, because the matter immediately solidifies upon the walls of the mould and does not allow the entrance of the air into the fluid mass, as is the case when ordinary bronze is cast under the same circumstances. With clay moulds however, this quality is unnecessary, because ordinary bronze does not comport itself in these moulds as when they are sand. Zinc is also alloyed with bronze in certain proportions, and communicates similar results.

Lead is not an advantageous ingredient in bronze, because it is readily oxidized, and hence augments the loss in the other metals by facilitating their combination also with oxygen; besides, it has a tendency of precipitating the copper with it towards the bottom of the casting, thus producing great inequalities if the object be large.

For many of the uses to which bronze is applied in the arts its composition is altered; thus, for wheel boxes or sockets the alloy contains—

Copper,	80
Tin,	18
Zinc,	2
	100

The fracture of this alloy is nearly white; it has a dry grain, and is very hard, but still may be worked. The zinc is added with the view of preventing cracks, which are apt to form in the casting owing to the contraction of the alloy upon cooling.

Another alloy intended for bearings has the following composition:—

Copper	82
Tin,	16
Zinc,	2
	100

This is somewhat more malleable than the preceding, so that when the collar is being forced on to its place it is less liable to break.

An alloy, when required to resist powerful friction and sudden shocks, is made of the annexed proportions, namely—

Copper,	83·0
Tin,	15·0
Zinc,	1·5
Lead,	0·5
	100·0

For pump-boxes and balls, and such articles as require to be brazed or soldered, the proportions are—

Copper,	87
Tin	12
Antimony,	1
	100

This alloy when broken presents a reddish fracture with a fine grain. It is malleable, but not sufficiently so as to answer for the material of stopcocks, pump-valves, and the like, which are subject to receive concussions, &c. These are better when made of bronze containing—

Copper,	88
Tin,	10
Zinc,	2
	100

This alloy has a fine grain, and is capable of receiving a high polish; it has a reddish colour.

The furnaces used in bronze casting vary in shape according as the work to be done is large or small. For very large castings the furnaces are either completely circular or at least oval; but for ordinary work they are lengthened out as in figs. 5, 6, 7, 8, which depict the forms used ordinarily. The same letters apply to each figure:—*a* is the fire-grate; *b*, the hearth; *c*, the opening through which the melted metal is run off; *d*, the door through which the metal is introduced and worked; *e*, the flue leading to the chimney shaft; *f*, the fire door.

Fig. 5.

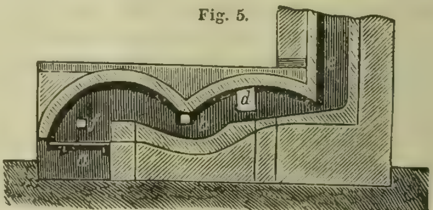


Fig. 6.

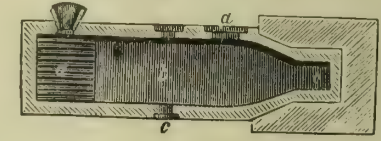


Fig. 7.

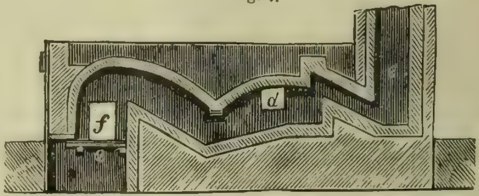
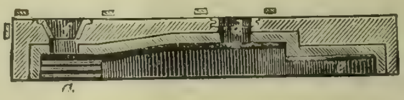


Fig. 8.



The bronze intended for medals is generally melted in small crucibles, and then cast in a mould made of sand. This is constructed of two parts or frames; the lower one, filled with the fine sand slightly moistened, is sprinkled over with ground charcoal, and the model either in wood or metal pressed down to half its thickness; the top of this is likewise covered with the powdered charcoal as before, and the superior frame pressed upon it, and secured in its place. Three small openings are formed in the sides of the frame, by laying the one end of iron or brass wire against the model, the other passing out of the frames, all of which are withdrawn as soon as the frames are secured to one another. In one of these a small tube is inserted for the purpose of introducing the metal, and the other two serve for carrying any vapour from the interior during the drying, to which it must now be subjected. To expedite this part of the work, it would be well to use only as much material as will be sufficient to resist the action of the metal, and also it hastens the desiccation to have the exterior coating composed of coarse sand, for then the aqueous vapour escapes with greater facility. Another point of economy is to cast the model and the feeding jet in some metal which will be able to resist the pressure of the moulding frames, so as to avoid the inconvenience and injury which sometimes arise from the drawing of the wire already spoken of; in doing so however, one moulding is sacrificed, but the advantages gained compensate for this. Although charcoal powder may be effectually used for strewing over the moist moulding frames, finely-ground bone ash, powdered slate, and the like, may likewise be employed; yet the first is to be preferred when it can be conveniently obtained, because, being soluble in hydrochloric acid, it can be removed by this means from the medal, and thus its cleaning is performed with facility.

The other opening by which the moisture or other vapours flow out must always be formed with the wire. Both this and the jet should be proportionate to the size of the casting, more especially the latter. The jet can be made to communicate with the model in two ways: either by the lower part in the form of a siphon, or by the upper in the usual manner. When the siphon form is used, the metal must be cast at a higher degree of heat than in the other, because of the length it has to travel before it enters the mould; and although, by filling the latter from beneath, it allows the moisture and air to escape more freely than otherwise, yet the greater heat is productive of inconvenience by giving porous castings, which is not the case with the other kind of jet. Besides these mentioned, there is another difficulty to be contended with in casting the metal, and this is, that the cast has never that strict identity with the model, in dimensions and the particulars of outline, which it is necessary that it should possess. This arises from the circumstance that the metal, in the act of cooling, contracts very much, and therefore, when the casting and mould are placed adjacent to one another, a marked difference is visible; but after being submitted to the pressure of sinking the die, it becomes more apparent. It may, however, be remedied by making the mould sufficiently large to compensate for the contraction which takes place. An exterior coating of a different body to the model has been found to answer well; lead paper has been proposed, but on account of the inconvenience which it necessarily offers, it cannot be satisfactorily managed.

As a substitute, recourse is had to tinning the model, and although the coat thus deposited is very small, yet it is sufficient to make up for the contraction, and besides, it contributes to remove all the slight inequalities of its surface, which, unless prevented, would be impressed upon the casting. All these particulars being carefully noted and observed, the compound metal, which should be fused in quantities of 10 or 12 lbs. in crucibles, heated by preference in a small wind furnace, is poured into the moulds at such a degree of heat as will not injure their outline. This point can only be arrived at by practice, which may be assisted by the following particulars:—If the metal be too cold, it flows badly in the mould, and the casting appears pasty; if too hot, it will act upon the moisture of the sand, and disengage vapours which will give a blistered irregular surface to the object cast. When the metal is heated to its proper degree for casting, it is found coated with a layer of oxide which has a smooth even surface; if this be removed, and the metal examined, it appears of a brilliant white. If the heat be too feeble the oxide on the surface will not be smooth, but present an uneven tarnished appearance; on the contrary, if the temperature be too powerful, the oxide enters into fusion, and appears like the metal, quite luminous.

As soon as the moulds are filled, the castings should be removed with all possible speed, in order that they may be thrown into water for the purpose of annealing; it this be neglected, and they are allowed to cool, they must be again heated to give the tempering necessary for their being worked under the die. After the impression is received, they are again heated to regain the peculiar hardness and durability of the bronze.

This terminates the work of casting medals or coin, but before they are laid aside it is customary to give them the finish, in order to make them resemble the ancient bronzes. This is done by boiling the medals, &c., in a solution of chloride of ammonium and acetate of copper. A film of oxide of copper is thus deposited upon their surface, the colour of which is more or less intense, according to its thickness. If the composition of the medal be rich in tin this process is not very successful; should zinc also enter into it as a constituent it can be effected by rubbing the surface with a powder prepared of sand and a copper salt mixed. Sometimes this is prepared by taking the following proportions of the ingredients named as under, digesting the whole in a bath of dilute nitric acid, and applying the solution with a brush. The mixture for antique bronze is—

Ordinary vinegar,	0·90
Chloride of ammonium,	0·09
Powdered green,	0·01
	1·00

For Florentine bronze the ingredients are—

Alcohol..	0·80
Red lead,	0·20
	1·00

Digested as above described in dilute acid before being applied.

GUN METAL.—This variety of bronze is formed of 88 to 90 parts of copper and 9 to 12 of tin, and from these proportions the founder very seldom deviates, although the constitents must be varied according to the size and nature of the casting. It is absolutely necessary that the admixture should be quite pure, for the smallest admixture of sulphur, lead, iron, or arsenic, would cause serious injury, and probably render the cannon useless. Lead, when combined with copper and tin, forms a soft alloy greatly deficient in tenacity, which is liable to fuse at the temperature developed by the explosion of the charge in the gun, and thus to occasion inequalities which eventually destroy accuracy of aim. Again, if sulphur, arsenic, &c., be present, they render the alloy brittle, and consequently unable to withstand the shock of the discharge.

The absence of these substances does not, however, insure the freedom from serious defects which often arise from over-hardness and want of tenacity in the alloy. By augmenting the quantity of the tin the hardness of the alloy is increased, but at the same time the homogeneousness of the alloy is more or less diminished when the weight of the alloyed metal exceeds a certain limit; since, although the two ingredients may be proportioned in the best possible way, yet during the casting the heavier metals gravitate to the bottom, giving rise to a more fusible compound in the superior part, which necessarily must contain more tin than it would do were the mixture homogeneous. This parting of the metals often occasions serious defects in the castings. When parts of the gun contain an excess of tin, and are consequently easily melted, these assimilate the sulphur in the gunpowder at the moment of explosion, and give rise to cavities of sulphide of tin which quickly occasions incrustations. Indeed, the most serious defects of cannon arise from the change which the metal undergoes in the mould. To some extent this evil has been overcome by the addition of 0·12 to 0·5 per cent. of phosphorus.

This defect is also to a certain extent remedied by cooling the metal to a certain point before allowing it to fall into the mould, and effecting the cooling by a certain period; the parting of the metals is thus in a great measure prevented.

Experience has proved that one alloy will not answer equally well for ordnance of all sizes. For eight-pounders, or thereabouts, that which is best adapted is made from 92½ parts of copper and 7½ of tin.

Considerable loss is sustained in bronze casting, and a great overplus of metal has to be used; this, however, is for the most part recoverable. It is laid down as a rule that, to obtain a casting of 100 lbs. weight, no less than 220 lbs. of material must be employed. It is disposed of in the following manner:—

	Lbs.
Weight of casting,	100
Loss of bronze in the scoria,	12·5
Bronze wasted in the *debris*,	107·5
Bronze employed,	220

The loss of metal and temporary waste being so great, it is evident considerable practice must be brought to influence the proper management of the work. For greater facility rules have been laid down, whereby the quantity of material required to be operated upon, in order to produce a certain weight of castings, may be ascertained by comparison. It is stated that in each charge one-tenth of its weight of new or ingot copper should be used, and that the tin in the shape of ingots should form about 15 per cent. of this quantity.

The subjoined numbers express the proportions which are to be used in the constitution of—

Lbs.
2200 of casting, namely,

488 of ingot copper,
73 of ingot tin,
1769 of old pieces of bronze,
2556 of bronze in the waste attending the manufacture,

4886; total weight of the mixture employed.

The real loss attending the manufacture, under ordinary supervision and with due care, does not exceed 10 per cent., and rarely indeed amounts to this, more frequently bordering on 6. It is evident from this that the furnace must be of such capacity as will work the increased proportion of metal where large castings are made.

The following table from DUMAS shows the proportions which have been followed in the foundry at Toulouse for the manufacture of cannons:—

	Siege guns.		Field guns.		Campaign guns.		Howitzers.		Mortars.	
Calibre,	24	16	12	8	12	8	24	6	10	8
	pounds	pounds.	pounds.	pounds.	pounds.	pounds.	pounds.	pounds.	pounds.	pounds.
Weight of furnace charge,	13481	9812	7804	5336	5512	3748	4013	5556	5767	2324
Weight of casting,	8291	5821	4454	3153	2719	1883	3488	4932	5115	1883
Weight of excess of metal used in casting,	3528	2712	2359	1356	2159	1356	—	—	—	—
Weight of waste in channels, &c.,	330	320	309	298	309	298	298	309	309	309
Probable loss,	1332	959	772	529	325	211	227	315	143	132
Probable centesimal loss,	9·8	9·7	9·7	9·9	5·6	5·6	5·6	5·6	5·6	5·7

Cornish and Banca tin are preferred, being generally free from lead. Sometimes the manufacturer employs old tin, which usually contains a large proportion of lead; but in this case it is necessary that it should undergo a process of refining before it can be incorporated with the other constituents of gun metal. This is done in a manner analogous to that described for separating copper and silver, and is based upon the greater fusibility of an alloy of lead and tin than of the latter alone. By gently heating the metal in a reverberatory furnace the more fusible alloy of lead and tin will quickly begin to flow, leaving the most part of the tin behind and comparatively pure; this latter portion is then submitted to one or other of the usual methods for depriving it of traces of lead.

The materials being at hand and ready for fusion, the mould should be prepared so as to receive the metal when melted, to give it the proper shape. Much depends upon the proper construction of the moulds in getting the pieces free from defect. They should have sufficient solidity to prevent the melted metal altering them, and the air and other gases which are contained in them, or developed by the heated medium, should have ready means of egress; otherwise, if confined, they will either endanger the safety of the mould by their expansion, or render the casting vesicular and imperfect. The material employed is clay or sand. With these, a quantity of brick-dust, cow hair, and horse dung are incorporated, to give them tenacity, so that they may be able to resist the metal. Care should be taken that no lime or silicious oxide of iron enters into this mixture; because the first would cause the evolution of gaseous matters when the liquid metal comes in contact with it, and the other would enter into fusion; the defect of blistering would follow from the former, and loss of true outline would be the result of the latter.

The method of procedure is to grind the clay, or temper it very fine with the aid of moisture, and then mix four parts of this with one of dung, leaving the matter to rest for eight days or thereabouts. This loam is macerated with three-fourths of its weight of sand, to which about a sixth of hair has been added. Another mixture is composed of clay, two parts by measure, sand one, dung a half, and hair half a part, the whole being well commingled. In the preparation of this mixture, however, various proportions are taken by different parties, all of which may be suitable in certain cases.

Fine sand, mixed with gelatine or glue, is also used to communicate an even surface to the mould before depositing the wax upon it. This article is usually obtained by burning tanners' waste, and washing the ashes with water to remove alkalinity. The more distinct parts of the mould are constructed of a mixture of 2 parts of yellow wax and 1 of resin. After they are made in the usual manner, they are dried, so as to be ready to receive the melted metal.

Reverberatory furnaces are resorted to for making the alloy, of which two forms are in use. One of these has the hearth circular, while the other is of the elliptical shape. Wood is generally burned in those with a circular hearth, and coal in the other variety. Artificial blasts are not employed in either case; but the draught is increased as much as is required to generate the proper degree of heat, without admitting any oxygenous gases into the furnace, which would tend to scorify the metals. On this account the fire is situated in the arch of the furnace, and as a precautionary means the fuel is always kept in a thick stratum upon the grate, to deoxidize the air passing in for supplying the combustion. Some regard the furnaces with circular hearths as being more economical, on the ground that they hold more matter, and present a less surface than the other to the flame, and therefore the charge in them is less liable to oxidation than if the hearth were elliptical; also, that they produce a more cohesive bronze. On the contrary, it is acknowledged that the other effects the fusion of the charge more rapidly, and affords facilities for rabbling and poling, of which advantage cannot be taken in the foregoing; likewise, that it produces a more homogeneous alloy, and that the consumption of fuel is much less than in the round furnaces. When, however, much sulphurous matter is contained in the fuel, serious injury is caused thereby, inasmuch as it gives rise to the formation of sulphides of the metals, which render the alloy brittle and inelastic.

Fig. 9.

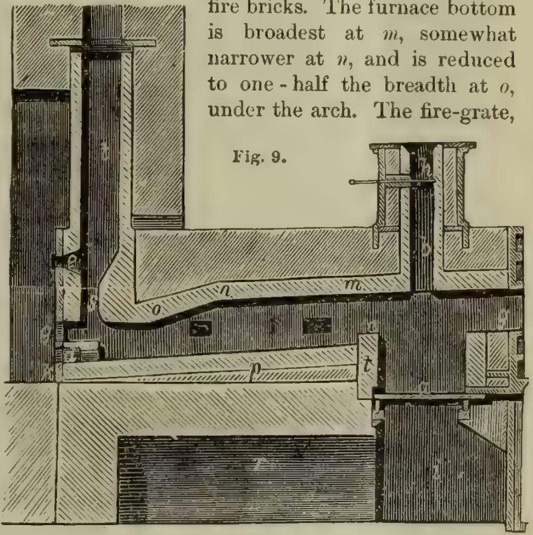
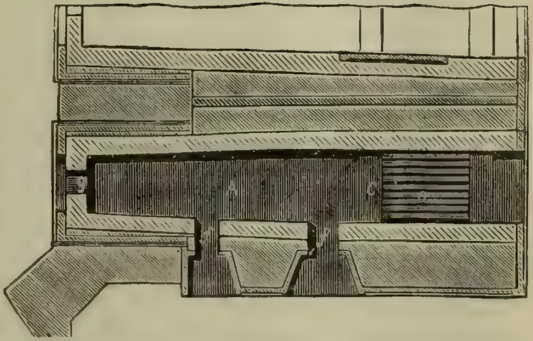


Fig. 10.



Figs. 9 and 10 show a modern furnace for melting gun metal. A is the hearth, which is constructed of fire bricks. The furnace bottom is broadest at *m*, somewhat narrower at *n*, and is reduced to one-half the breadth at *o*, under the arch. The fire-grate, *a*, is furnished with broad fire-bars; *i* is the ash-pit; *b* is the flue: it has a sliding damper at *h*; *c* is the fire-bridge beneath the furnace arch; *p* is the furnace bottom, sloping towards *d*, the taphole through which the charge is run out: this is closed by a door, *k*, in which is the opening *g*, through which the melting gun metal is stirred up and poled; *e* is another opening for occasional inspection of the charge; *s*, a channel supplying air to the furnace; *f f*, doors for removal of scoria, &c; *q*, an opening used when large pieces of metal have to be melted; *t*, the chimney shaft. Large pieces of metal are thrust in through an opening at *q*.

According to the extent of the foundry and the size of the castings, several furnaces, of various capacities, are requisite, the principal ones being destined for making the bronze, and the lesser for smelting the refuse matter of the manufactory, or purifying some of the substances which are to be operated upon. The three parts of the furnace which require especial attention are the fire, the hearth, and the chimney. With regard to the first of these, as already mentioned, the principal fact which deserves to be particularly noted is the regulation of the draught. One of the reasons for constructing the fire-door in the arch of the furnace is, that it may not interfere with the current of air passing through, which it would not fail to do if constructed at the side, as is customary in reverberatory furnaces. The ashpit is entirely inclosed with the same view, in order that the hot cinders which fall through the grate may not rarefy the current of air rushing to the fire, and cause a deficiency by this means from the actual volume necessary to maintain the proper temperature. To render this more effectual it should be rather spacious. The galleries, in like manner, should contract as they approach the fire, so that the current may be delivered as dense as possible.

The interior of the furnace in which the operation of smelting is conducted is generally composed of two planes, inclined towards the middle, thus offering by their intersection a cavity leading to the outlet through which the liquid alloy is drawn off when requisite. During the fusion the metal is watched and treated with the necessary attention through the doors already mentioned. A variable position and construction is given to the flues, according to the size of the furnace; their superior end borders upon the chimney, and their lower extremity is sloped, and partly dips into the molten bath, so that the flame has to traverse the whole surface of the hearth before its exit. It is needless to say that the entire surface of the interior of the furnace should be made of the very best refractory bricks, set in a cement which will likewise effectually resist the action of the fire. For greater security a coat of refractory lute is put on the interior superficies.

When the furnace is newly erected, or the luting is renewed, it retains a great deal of moisture, which necessarily should be expelled before operating upon the metals, otherwise, if allowed to remain, it would act injuriously upon the structure, causing it to crack and break in various parts. To effect the desiccation, the interior is filled with bricks, by piling them upon the hearth in such an open manner, that the flame and heated vapours from the fire will easily permeate the mass. The doors are closed by a few firebricks cemented together by mortar, and the fire, which may be of coal, wood, or charcoal, according to the kind of furnace, is then lighted. At first the heat should be very gentle, and as the excess of aqueous vapours is expelled, it may be gradually increased during eight or ten days, about which time it arrives at a white heat, which should be maintained for two days longer, or thereabouts. At the termination of this period it may be safely assumed that the whole is thoroughly baked. All the doors and other orifices are then opened, and the structure allowed to cool gradually. Sometimes it is necessary to repair the furnace by such a coating. This should be foreseen in its erection, and sufficient room left for the purpose. In the latter instance the baking need not be prolonged beyond three or four days.

The charging of the furnace follows the removal of the bricks from the interior by introducing, first, the ingots of copper, the fragments of old cannon, and other cupreous matters. As soon as these are liquefied the remainder necessary to make up the total, in the shape of scales and turnings from the hammer and lathe, together with the requisite weight of tin, is added. Before introducing these, however, it is customary to coat the hearth and the walls with moist cinders, in order to prevent contact of the bronze with the bottom and sides, to which, if this were neglected, it is apt to adhere. The mouth of the tap-hole is likewise closed with an iron plug coated with loam, so as to fit more accurately the orifice. In arranging the charge on the bed of the surface, the larger pieces are placed in such a position that they will receive most heat. Care should likewise be taken that the mouths of the flues are not blocked up. On the contrary, these should be left as free to act as possible; because the briskness of the combustion is dependent in a great measure upon them. On the Continent the furnaces are generally heated with wood, oak or beech being used according as the country will supply it, though in Belgium coal and coke is much used for fuel.

During the first few hours of the firing the heat is kept very moderate, so that the expulsion of the aqueous vapour, &c., may be very gradual. When the sole becomes heated the fire is urged more strongly, and the metal, which hitherto manifested no signs of its action, begins to assume an incipient redness. The flame, which also appeared dull and scarcely extended to the vent holes or flues, at this time becomes brighter and more enlarged, so that it rises to their upper end. By maintaining this temperature the metal reaches a white heat, and very soon begins to melt in part, and so continues till, at the end of seven or eight hours, it is entirely liquefied.

In the course of the operation it is observed that the bronze which forms part of the charge, before it becomes fluid, appears incandescent, the tin oozes from all the pores in drops, which unite and stream to the hollow of the hearth, carrying only a small portion of copper with them in combination. The operator takes care that all the matter is perfectly liquefied, by stirring in any particles which might remain at the sides and bottom of the molten bath.

When he is satisfied that all is melted he thrusts a long pole of birch wood into the mass, and stirs it about just as in the refining of copper. This causes a violent seething, and brings both the metals into more intimate contact, thus insuring more perfect combination than if they were left unmolested. The bath is likewise rendered more fluid, on account of the ebullition raising fresh metal to the surface, where it meets with greater heat; and unless the action of the pole were prolonged the inferior layers would not be sufficiently liquid, because the superior one, being more expanded on account of its contact with the high temperature of the fire, is specifically lighter; it would preserve itself at the surface, unless the mechanical action of poling instituted currents which would force the matter at the bottom to the surface to receive an equal amount of heat.

When the whole is in perfect fusion, the temperature being very elevated, the workman skims carefully the scoria which has risen to the surface during the poling. The heat of the fire is still maintained by the repeated addition of fresh fuel. The rabbling, poling, and skimming engage the whole attention as long as scoriæ are thrown off; and when these are for the most part removed, the fire being still urged to its highest limit, the tin necessary to make up the proper composition of the bronze is projected into the bath in the form of small ingots, to facilitate its rapid distribution throughout the mass. During this time, and successively to the period of casting, the fire and the poling are made to exert their utmost influence in keeping the molten mass as liquid and as homogeneous as possible.

To determine the moment most suitable for running off the fluid metal is a very critical point, and one that requires much skill and practice. Generally it is raised to the highest possible temperature under the circumstances, and it is thought that the more elevated the heat is the better; but even this, it is reasonable to suppose, will have its limit. When the metal is nearly ready, the workman finds that the spar of wood with which he effects the poling will feel light in his hand. It can then be thrust with facility into the bath, and its end will glide freely upon the bottom of the furnace. When withdrawn it retains very little metal, the chief portion falling off in small drops. The sound of the agitated matter is very clear. It may readily be thrown into numerous undulations, which as quickly subside. Fragments of lighted charcoal which float upon the mass move about very rapidly, especially towards the bridge of the furnace. Whenever a fresh supply of wood is thrown upon the fire it does not cause a disengagement of gases from the bath, but the flame which escapes by all the flues possesses a brilliant whiteness.

Preparations for the castings are being made five or six hours previous to the time in which this is to take place. The channel by which the fluid metal flows to the moulds is coated with loam and baked, first with a fire of wood and afterwards with one of charcoal or coke. The moulds must be left partly uncovered, so as to permit the escape of moisture more freely. These and the canal attached are carefully brushed, so as to remove all dust and extraneous particles of matter.

The iron plug which secured the tap-hole is then removed by appropriate means, and the metal allowed to flow out into receptacles in the channel, whence it is permitted to run into the moulds in succession till they are filled. During this part of the work much aqueous vapour and gases are disengaged by the superheated metal coming in contact with the mould, and cause great inconvenience and injury to the casting: their development may be prevented to some extent by taking care that no moisture can reach the mould by infiltration, and also by deferring the casting whilst the metal is too hot. When the jet appears of a bluish colour the material is highly fluid; but when it is bordering upon the point of congealing it assumes a violet tint, arising from an envelope of a yellowish-red, and is owing to a part of the metal solidifying. The vapours given off are apt to cause irregularities in the casting, if these were not prevented by pouring more metal into the inlets and keeping them quite full. It is customary, likewise, to throw some charcoal upon them, to keep them in a fluid state as long as any disengagement takes place, so that the metal in them may supply any vacancy caused either by the evolution of gas or the contraction during the cooling. After the metal has sufficiently congealed the partitions of the channel are removed, and likewise the brickwork and other appendages which were employed as means of security in the moulding; and after two or three hours the clay surrounding the casting at the top may be taken away, either wholly or in part. At the end of forty-eight hours or so, according to the size of the objects cast, they may be drawn, the earth and other extraneous matters being previously removed to the adjoining compartment. Owing to the pressure which is exerted upon the moulds, much metal percolates them. This is afterwards recovered by smelting those parts in which it is contained in a small furnace devoted to this purpose. The various other products of the channels, and the excess of material appended to the objects, are subsequently used up with another charge.

The guns are next treated by mechanical agency to give them a smooth exterior, and then bored in the usual way, and finally proved by various tests. The mode of proceeding above described applies equally to the casting of bronze in general.

Though steel has to a great extent superseded bronze in the manufacture of cannon, yet the cheapness and the facility with which guns can be made by casting in comparison with welding have led to many endeavours on the part of continental military engineers to increase the toughness of gun metal, so that it might be able to bear greater charges of powder.

In Russia experiments were made on the increased strain bronze was able to bear if it had been subjected to pressure whilst still in the liquid state. Guns of chilled bronze were exhibited at the Vienna exhibition, 1873, by Lavessière, of Paris. The "chilled bronze" was, however, found to be deficient in elasticity and hardness. To overcome these defects General Von Uchatius, director of the Imperial Arsenal at Vienna, proposed to roll the chilled bronze, or rather gun metal, when cold. The results of his experiments showed that it was possible to roll the chilled bronze when cold up to an elongation of 100 per cent. without the least crack being made; and that with an elongation of only 20 per cent. the alloy obtained the hardness, elasticity, and strength of steel. The gun metal thus treated contained 90 parts of copper to 10 of tin, and was subjected to a pressure of 80,000 kilos. immediately after it had been cast into moulds.

These experiments brought to light a fact of high importance in metallurgical industries, viz., that the elasticity of all tough materials increases rapidly after they have been subjected to a force exceeding the elastic strength of the material. Thus, chilled bronze reaches its elastic limit under a strain of 400 kilos., corresponding to an elongation of 0·0004 of the original length; whilst after having been submitted to a tension corresponding to a permanent set of 0·004 of the original length the elastic limit of the material is raised to 1600 kilos., with a corresponding elastic elongation of 0·00192 of the original length. After a careful consideration, General Von Uchatius decided that the work done by the powder in the powder-chambers to the detriment of the guns might be anticipated in the manufacture of the gun by compressing the interior of the bore mechanically to a degree exceeding that produced by the explosion of the powder, and thus raising the elastic limits of those portions which have to resist the force of the explosion; *i.e.*, the material about the bore might be treated in a manner analogous to the rolling process above spoken of, until the requisite degree of hardness was obtained.

The bronze alloys best suited for cannon he found to be:—

10 per cent. tin, 90 per cent. copper.
8 " 92 "
6 " 94 "

Moreover, uniformity of quality throughout the casting was attainable by simultaneous inside cooling, *i.e.*, by the chilling of the bore. A current of air and a stream of water having respectively proved unsuitable for this purpose, solid cores of various metals were tried, and it was at length found that by using wrought-copper cores of 50 mm. diameter, perfectly good and reliable results could be attained.

The mode of gun-making at last adopted is as follows:—Guns of the desired size are cast in iron moulds in the ordinary way, but have their core "chilled" by a copper core. These hollow ingots are then bored out to a calibre of 80 mm., with an outside diameter of 260 mm., and are each 300 mm. long. At one end, the outside is turned to a diameter of 180 mm., corresponding to that of a finished field-gun, and the hollow ingot placed vertically upon a circular base-plate with a corresponding hole, and a conical piston of hardened steel forced through the tube by means of a powerful hydraulic press. As the tube opposes a resistance which increases with the widening of the bore, the difference in the diameters of the conical pistons following each other has to be reduced accordingly; so that with six pistons forced through the bore, the first one has a diameter 2 mm. larger than that of the bore, whilst the last is only ½ mm. larger than the preceding one. By this process the bore, which originally had a calibre of 88 mm., is enlarged 2 per cent. Its surface, when tested with the compressor, shows a hardness equal to that of gun-steel, and it was also observed that at the turned portion of the tube the interior had acquired the same hardness as the rest of the bore.

A gun thus constructed was fired 1800 times with the full service charge, without the least alteration being perceptible in its dimensions and general appearance, or in its shooting powers.

This mode of manufacture possesses the additional advantages that by it all unsound parts are easily detected, for wherever there exists a fault in the material, or where the bronze is not of perfect quality, the act of drawing immediately produces cracks and fissures. Another highly important point is the fact, that after the piston has been forced through the bore, the diameter of the latter contracts to 0·004 of the diameter within the elastic limit, proving that the different parts of the gun are in a state of elastic compression, which equals, according to careful calculations, a radial central pressure of about 2400 atmospheres. To prove this elastic compression to be acting throughout the whole mass, General Von Uchatius had a ring turned off one end of the tube until a small circle of metal on the inside of the tube alone kept the ring on the main tube. Before the chisel severed this last connecting circle, the ring spontaneously sprang off, and showed a smaller calibre bore than the tube from which it was taken.

The 8 per cent. bronze appears to be the best suited to the manufacture of guns, as the inner chilling can be effected much more easily than with the 10 per cent. bronze, and does not require the addition of so much copper as the 6 per cent. bronze. It is also the cheapest of these three alloys.

Guns manufactured as above described can be compared to coiled steel tubes, as they have the same degree of hardness, homogeneity, and strength in the bore as the latter, and as the radial pressure to the centre of the gun is obtained beforehand by the treatment of the material itself.

The quality of the bronze varies from the outside to the bore in direct proportion to the stress the gun has to bear. The elasticity of the inner parts and the toughness of the outer surface are far greater than that of steel.

The neutral axis, where the explosive force of the charge and the opposing elastic pressure of the material are in equilibrium, lies very near the bore in steel-bronze guns. To make such a gun fly to pieces the elasticity of the whole material must be overcome simultaneously, and then the great toughness of the outer portions, bearing extension to 70 per cent. without breakage, would still offer opposition to the explosive force. In coiled guns, on the contrary, the neutral axis lies between the tube and the coils, and the latter have to bear the full force of the explosion.

TABLE SHOWING THE RESULTS OF TESTS WITH THE DIFFERENT MATERIALS FOR THE MANUFACTURE OF ORDNANCE.

Load in Kilogrammes, per one Square Centimetre of Section.	Cast-iron frame, 9-inch gun.		Bronze.						Wrought iron from Styria in rods of small section.		Krupp steel from 6-pounder.		Steel-bronze near the			
			Common form of 8-pounder.		Chilled.								Bore.		Outside.	
					Cast.		Rolled.									
Elongation in 0·00001 of original length.	Elastic.	Permanent.	Elastic.	Permanent.	Elastic.	Permanent.	Elastic.	Permanent.	Elastic.	Permanent.	Elastic.	Permanent.	Elastic.	Permanent.	Elastic.	Permanent.
100	2	0	10	0	8	0	2	0	4	0	1	0	3	0	3	0
200	10	0	15	0	15	0	7	0	9	0	3	0	5	0	14	0
300	15	0	25	0	25	0	10	0	11	0	7	0	8	0	25	0
400	22	0	35	0	40	0	22	0	14	0	12	0	14	0	35	0
500	27	0	47	1	53	2	37	0	18	0	16	0	20	0	55	0
600	33	0	56	4	62	4	50	0	22	0	20	0	26	0	65	0
700	38	2	66	7	70	6	60	0	24	0	25	0	33	0	78	0
800	47	4	77	11	79	8	73	0	27	0	30	0	40	0	86	3
900	54	5	88	20	87	10	86	0	31	0	34	0	48	0	93	7
1,000	61	6	101	32	100	13	96	0	35	0	39	3	54	0	103	12
1,100	68	8	110	52	108	22	107	0	37	0	44	5	60	0	112	18
1,200	76	10	120	96	115	47	117	0	40	2	50	7	66	0	129	26
1,300	84	14	—	—	130	117	128	0	42	3	55	10	73	0	135	45
1,400	92	19	—	—	150	327	139	0	45	4	60	14	80	0	160	125
1,500	101	24	—	—	170	380	149	0	48	5	65	20	88	0	—	—
1,600	110	30	—	—	192	441	159	0	52	6	71	31	95	0	—	—
1,700	120	35	—	—	—	—	170	0	57	7	76	38	102	0	—	—
1,800	130	50	—	—	—	—	179	2	62	8	81	48	110	0	—	—
1,900	142	65	—	—	—	—	193	5	67	8	85	120	115	2	—	—
2,000	157	81	—	—	—	—	203	8	72	9	90	252	121	3	—	—
2,100	—	—	—	—	—	—	215	10	77	10	98	360	127	5	—	—
2,200	—	—	—	—	—	—	222	12	82	12	110	586	134	7	—	—
2,300	—	—	—	—	—	—	239	14	88	14	—	—	142	8	—	—
2,400	—	—	—	—	—	—	252	18	93	16	—	—	152	10	—	—
Absolute strength,	2420		2260		3050		5066		4700		4800		4875		3300	
Limit of elasticity,	600		400		400		1700		1100		900		1800		700	
Elongation in per cent. of original length, At the limit of elasticity	0·033		0·035		0·040		0·170		0·037		0·034		0·110		0·075	
Elongation in per cent. of original length, At rupture,	0·40		15·0		40·0		22·0		22·4		21·4		2·5		40·0	
Section at point of rupture,	0·96		0·66		0·54		0·96		0·62		0·50		0·96		0·58	
Hardness (length of chisel-cut),	10·2		12·5		12·5		10·2		10·5		10·5		10·5		12·0	
Number of blows of 1·2 kilogrammes required to break a test-bar with a sectional area of ·5 sq. centimétres,	1		1·10		—		—		—		209		255		146	

The bronze-melting furnace in use at the Royal Foundry at Munich, for casting statuary and objects of art, is shown in Figs. 11 and 12. Fig. 11 is a vertical section at *x*, fig. 12. Fig. 12 a horizontal section, along the line *y y*, fig. 11. The same letters apply to each engraving. The fire grate is at *a*; *b* is the melting hearth, *c* the outlet for the melted metal, *d*, opening for carrying off the products of combustion, *e* the founding pit, *f* the smoke shaft, and *g* the charging door.

PHOSPHOR BRONZE.—Combinations of phosphorus with copper, zinc, or other metals, have long been known, but it is only since the carefully conducted and very exhaustive experiments of Messrs. MONTEFIORE and KÜNZEL, in 1869 and 1870, at Liége, have been completed that phosphor bronze, an alloy of copper, tin, and phosphorus, has become known and applied to art and industry.

From the description of bronze founding it may be gathered that there are several well-defined difficulties in making a uniform alloy. These are:—(1) Impurities in the metals, which seriously affect the physical properties of the copper. (2) Oxidation to variable extents, occurring in the melting. (3) Absorption of oxygen, or combination or admixture of oxides with the alloy, produced during the melting from the constituent metals, or their combination with minute doses of carbon or sulphur. (4) Evolution of oxygen (possibly of other gases) and expulsion of the oxides more or less during the cooling of the alloy, rendering it porous or "blown." (5) Segregation in cooling of the normal alloy, if attained ($17\ Cu + Sn. = 90{\cdot}2\ Cu + 9{\cdot}88\ Sn$), into several alloys, some brittle, some soft, unequally diffused through the body of the casting.

The first has practically vanished through metallurgic improvements. The second must remain a difficulty always, only to be mitigated by operating upon a very large scale, and always with furnaces the same in construction and working, and with the same fuel. The third and fourth are to a great extent met by the introduction of phosphorus into the alloy; whilst the fifth and last may undoubtedly be much lessened, if not removed, by casting the objects in massive iron moulds, instead of those of loam, so as to "chill," or suddenly cool, and solidify the alloy, before time has been given for its degregation.

Copper and phosphorus combine with facility at temperatures sufficiently high to secure intimate contact of the two elements. By carefully dropping phosphorus on melted copper in a crucible the metal may be made to take up as much as 11 per cent. The fusibility of the copper is much increased, and it becomes at the same time so extremely hard that it can scarcely be touched by a file.

Fig. 11.

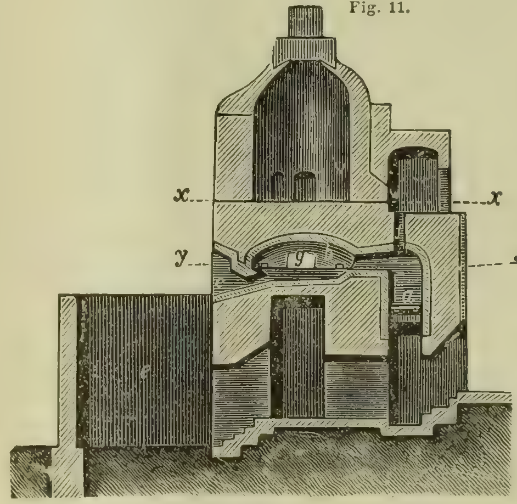
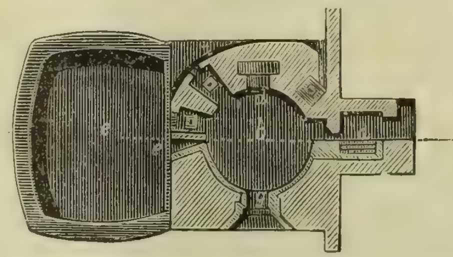


Fig. 12.



Copper phosphide was first formed about the middle of last century by Macquer, and somewhat later studied by Bertrand Pelletier, and also by Sage. The latter states that 92·3 parts copper and 7·7 phosphorus is a stable if not a definite compound, hard and brittle, and with the grain and colour of steel, and that with much less phosphorus the combination is malleable and yellow, so that, say Aiken ("Chemical Dictionary," 1807), "it may be hereafter found useful in manufactures." H. Rose formed three or four definite phosphurets of copper, and described their properties in "Pogg.'s Ann.," vols. iv. xiv. xxiv. Berthier ("Essaies," tome ii.) restudied the subject, and described some of the properties of these compounds. Percy ("Metallurgy," vol. i.) formed some of them, and has described their properties. Shroeter also prepared compounds of copper and phosphorus which he considered to be definite phosphides. These were dicupric phosphide, Cu_2P_2, which he believed he obtained by reducing dicupric phosphate by passing hydrogen over it. When mixed with chlorate of potash and sulphide of copper, or pounded coke, to increase its conducting power, dicupric phosphide forms the fuse compound which Professor Abel has found best suited for firing charges of gunpowder by magneto-electricity.

Tricupric phosphide, Cu_6P_2, was stated by H. Rose to be produced by passing phosphuretted hydrogen over heated copper protochloride, or into a solution of sulphate of copper. The first process yields it as a black powder, the second as a black flocculent precipitate, which on heating in vacuo assumes the red colour of precipitated copper. Tricupric phosphide is more fusible than copper, but does not melt at the fusing point of glass.

Tricuprous phosphide (Cu_3P_2) is obtained by passing phosphuretted hydrogen over cuprous chloride. It is a black powder, which after strong ignition turns grey, and assumes a metallic lustre.

Professor Abel has confirmed Rose's experiments with regard to the phosphides Cu_6P_2 and Cu_3P_2, and has shown that the dicupric phosphide cannot be produced by the action of hydrogen on the diphosphate, the proportion of phosphorus in the product, after separation of the phosphoric acid, being between 3 and 8 per cent.

He also found that dicupric phosphide (Cu_2P_2) is converted into hexcupric phosphide (Cu_6P_2) by ignition, either alone or in hydrogen gas. The hexcupric phosphide contains 14 per cent. of phosphorus.

Phosphorus vapour passed over copper at a low red heat causes incandescence, and forms a fused mass of a steel-grey colour, which contains 12·2 to 13·5 per cent. of phosphorus.

By adding phosphorus to fused copper, and stirring the mass till it is nearly cold, a product is obtained consisting of three layers, the uppermost being white, very hard, and brittle, with shining crystalline fracture, and containing from 7 to 12 per cent. of phosphorus; the middle layer being grey, with granular fracture, and containing 4 to 6 per cent. phosphorus (this forms the principal part of the whole mass); while the lowest, which is insignificant in quantity, consists of nearly pure copper, containing only 0·5 per cent. phosphorus.

By adding phosphorus to copper, melted at such a temperature that part of it still remains solid, Abel produced a compound containing from 2 to 4·7 per cent. phosphorus, which by casting in iron moulds he obtained in homogeneous hard masses, having a fine-grained fracture, like that of bell-metal, but quickly tarnishing. By fusing this compound with pure copper, other compounds, containing smaller proportions of phosphorus, were obtained, which exhibited greater tenacity than ordinary gun metal.

In 1865 ABEL published the results which he had obtained in the Woolwich Arsenal Laboratory (*Chemical News*, vol. xii. p. 172, and "Report of the British Association," 1865). These compounds were tested as to tensile strength at the arsenal with the following results:—

RESISTANCE PER SQUARE INCH TO SLOWLY APPLIED STRAINS.

	Lbs. per square inch.
Gun bronze,..............................	32.000
Copper,....................................	25.000
Copper + 0·5 per cent. phosphorus,........	38,389
Copper + 1·4 per cent. phosphorus,........	47,000

The mode of casting has, however, considerable influence on the physical properties of the phosphoretted copper. ABEL found that copper containing 1 per cent. of phosphorus when cast in an iron mould exhibited a tenacity of 36,893 lbs. to the square inch, whereas when cast in a sand mould its tenacity was only 13,959 lbs. to the square inch. Altogether he considered phosphoretted copper as not adapted for casting, as it contracts very much in solidifying, and when cast in moulds of sand or loam the casting is very porous. By fusing the phosphoretted copper with iron, the greater part of the phosphorus is removed with formation of iron phosphide, which separates as a distinct layer, while the copper becomes alloyed with iron.

Mr. ABEL does not appear to have followed up his research by investigating the compounds of bronze and phosphorus, and has not published any further experiments, though in a communication to the War Office, dated June 27, 1870, he stated that he had subsequently to his experiments above, made some on phosphorized bronze, and "that the properties of the material were of a very promising nature." Mr. PARKES, of Birmingham, about this time took out two patents for the employment of phosphorized copper and *brass*. He does not mention *bronze*.

In 1854 M. RUOLZ, of the Orleans Railway, observed the great increase of tenacity and resistance to abrasion given to bronze by phosphorus, and in 1856 had some 4-pounder bronze guns cast containing 0·6 per cent. of phosphorus; these were experimented on by the French artillery with, on the whole, favourable results.

Between 1868 and 1870 Messers. MONTEFIORE-LEVI and KÜNZEL engaged in experimental researches on the improvement of gun bronze, which embraced the following heads of research:—Binary alloys of copper with manganese and with nickel. Ternary alloys of bronze with nickel, iron, and zinc. Combinations of phosphorus with copper and with bronze.

As regards the purity of the several metals employed, the copper was either "best selected" from PASCOE, GRENFELL, & Co., Swansea, or punchings from the plate-copper of locomotive fire-boxes. The tin was Banca, or that specially purified at the works of Val Benoit, whence also came the nickel, which, except a trace of sulphur and 0·3 per cent. of iron, was chemically pure. The manganese alloys were formed from a manganiferous copper of ascertained constitution produced by the reduction of the mixed oxides of copper and manganese, both being pure, in a cupola, which, we may remark, must have contained a sensible quantity of carbon and of other bodies if the cupola fuel was coke. In the phosphorus experiments, that body was brought into combination either in the state of a previously formed rich phosphuret of copper or one of tin. The alloys were all melted in plumbago crucibles under a covering of charcoal. Analyses of the alloys formed showed the extreme difficulty of procuring, after casting, alloys of predetermined constitution; in some cases as many as ninety proof pieces were cast before one was obtained having the assigned constitution within limits of one-tenth per cent. The proof bars were cast in a two part, nearly cylindrical, cast-iron ingot mould, weighing about 170 lbs., and producing a very slightly conical ingot, with an enlargement at the head, of about 19 in. long by about 2¼ in. diameter. From these cylindric bars for testing, provided with shoulders to be gripped at both ends, were turned, each of very nearly 1·10 in. diameter, by 10·50 in. length between the shoulders.

The important question, first entered upon by DUSSAUSOI, of the effects of pouring alloys such as these at different temperatures, and cooling them at different rates, was inquired into with a good deal of care. They determined the temperature of the liquid metals at the moment of pouring by casting into a known weight of water at a known temperature, a given weight of the liquid metal whose composition was assumed known, and the specific heat of its constituents also. Then, from the equation

$$x = \frac{P^1 (t^1 - t)}{P c} + t_1$$

in which P^1 is the weight of water; P, that of the fluid metal cast into it; t = the temperature of the water before, and t^1 that after the casting into it, the temperature of the liquid metal was calculated. This is, in fact, the "method of mixture" in which, knowing the specific heats, we can find the temperature, or *vice versâ*. Though this equation did not afford precise results, it was, however, the only method practically available, and the results are valuable as an instalment upon an almost previously untouched matter of precise inquiry.

The "liquation" or segregation of these alloys was ascertained by melting 10 kilos. of each alloy in a plumbago crucible, permitting the liquid metal to cool until a crust formed; then breaking this and pouring out from the surrounding metallic shell the liquid contents. The crucible and shell were then further slowly cooled; and if, prior to complete solidification, a further segregation took place from the shell, it was poured out, and all these different alloys were submitted to analysis.

The experiments made upon ordinary gun-metal were as follows:—

Bronze which when first alloyed contained—

	Tin.		Copper.
Metal (originally),................	10·10	+	89·90
After one remelting, contained......	9·82	+	90·18
" two " "	9·40	+	90·60
" three " "	9·16	+	90·84
" four " "	8·52	+	91·48

As regards the change of composition due to repeated melting, the tin thus continually decreases in relation to the copper by oxidation; and assuming, as we are justified in doing, that some of the oxide of tin is involved *as oxide*, if not combined *as such* with the alloy, the actual amount of *metallic* tin present in each case is *less* than that assigned by the above table—which, as deduced from analysis, gives the *whole* of the tin present in the alloy, in whatsoever state.

The experiments made in the segregation (*liquation*) of the ordinary bronze into different alloys in slow cooling generally agree with what had been already indicated by Dussausoi and Mallet. The results of these experiments are, that ordinary bronze, by slow cooling, segregates into several different alloys; that richest in copper first. Those subsequently segregated, the authors think, have not any constant constitution. Finally, there is segregated an alloy of nearly constant constitution, which approaches to that of 18 per cent. of tin and 82 of copper.

The manganesiferous alloys they concluded to be wholly useless for gun metal, as indeed those of nickel and of iron likewise, though in certain proportions they present very high coefficients of rupture. But the ready oxidability of manganese at high temperatures as compared with copper produces such uncertainty in the results that, independently of their expensive character, these alloys have not come into use, though it is proved that manganese does exalt the hardness and elasticity of bronze.

As to nickel, they found its alloy with copper more absorptive of oxygen than copper itself, and they could only with difficulty obtain some sound test bars, containing a low percentage of nickel, by casting the alloy in a red-hot ingot mould. It is a remarkable fact that nickel in large proportions should play the same part that tin does when either is alloyed with copper, in causing the compound to absorb oxygen when in fusion and give it up on consolidation. Copper with 20 per cent. or more of bell metal is far *more* absorptive of oxygen than copper itself; and it has been observed that when large bells are cast from nearly pure copper and tin, they are always more or less full of microscopic vesicles, whilst a very small percentage of zinc and of lead present seems to prevent this.

In the ternary alloys of bronze with nickel the physical effects of the latter metal are not striking, and the results as to tension not promising. And, as respects bronze with iron, these results are not more so, resulting from the far more rapid oxidability of iron at high temperatures, than either of the other two metals present.

The addition of minute doses of zinc to ordinary bronze (2 per cent.) they found augmented the resistance to rupture (by reducing involved oxides), but it softens the alloy, and causes it to lose its elasticity with great rapidity when near the elastic limit.

The beneficial part which zinc plays is, like that of phosphorus, that of a deoxidant, and it was simply as such that Montefiore-Levi and Künzel first proposed to themselves to employ it. Finding, however, that phosphorus in higher proportions sensibly hardened as well as increased the tenacity both of copper and of bronze, they added larger doses.

In remelting old bronze there is much difficulty in determining analytically the proportion of oxides, or of oxygen, mixed up or combined with the metal, and it has been found that the more oxide was thus enveloped the less was the amount of segregation in cooling; also, that *brassage*—that is, stirring about (as in "poling" copper) a large mass of old bronze remelted, and without charcoal covering, in the furnace with a pole of wood (generally of birch unseasoned)—has but slight effect in eliminating the oxide; and here comes in for the first time the application of phosphorus. By its introduction in extremely feeble proportion indirect evidence is afforded that oxygen *is* involved in some form in the remelted bronze, and Montefiore-Levi and Künzel argue, that it exists in the metal not as occluded oxygen, but as oxide of tin. In whatever be its state, the addition of a feeble dose of phosphorus appears to remove it, if not completely, yet much more completely than any amount of poling (brassage); so that whilst the elastic and rupturing resistances of old bronze containing very much oxide were exalted from 3 to 8·5 per cent. by brassage, these were increased from 9 to 36 per cent. respectively by the addition of only about as much phosphorus as eliminated the oxygen or oxide.

Shavings of old bronze were melted, and a bar thereof cast at 1595° C. The remaining liquid bronze was stirred with a wooden stick (poled), and a second bar cast at 1668° C. The remaining metal was deoxidized with phosphorus and a bar then cast at 1614°. The three castings were thus made out of the same crucible and in the same manner into three iron moulds. The results were as follows:—

Nature of the Bronze.	Absolute Resistance.	Elastic Resistance.	Lengthening until Rupture.	Diminution of Section.
			Per Cent.	Per Cent.
Old bronze,.	1613	1209	2	3·2
Old bronze, poled,	1755	1244	2·8	3·2
Old bronze deoxidized with phosphorus,........	2384	1356	6·8	6·7

Thus, by the entire reduction the old bronze has tripled its tenacity and considerably augmented its absolute resistance.

Having so far succeeded in eliminating the oxides from the bronze, the inventors showed that, by the further addition of from 0·1 to 5·2 of phosphorus to the bronze alloy, the qualities of the latter become more and more changed, the colour becomes evener, the grain or fracture finer, and the elasticity and resistance to strain and compression are considerably increased; it attains a great fluidity when melted. As minute quantities of carbon alter the physical properties of iron, so a minute quantity of phosphorus so changes the character of bronze that what steel is to wrought iron, phosphor bronze is to ordinary bronze.

Phosphor bronze is manufactured commercially by the admixture of copper phosphide or tin phosphide, with the required quantities of melted copper and tin. The smelting furnaces are similar to those used for smelting bronze or brass.

The bronze is first melted, and then the copper or tin phosphide (by preference the latter) added, little by little, with much stirring.

This phosphide, Sn_9P, containing 6 per cent. phosphorus, is prepared by gently heating together phosphorus and spongy tin in a tightly-closed crucible. The spongy tin is prepared by precipitating a solution of tin chloride with metallic zinc. The phosphorus is first placed at the bottom of the cold crucible, which is then filled up with moist precipitated tin. Heat is applied until fusion takes place, and no more phosphorus flame appears. On cooling, the tin phosphide is found in large crystals, which have a melting point much above that of pure tin.

The qualities of phosphor bronze have been largely tested and tabulated by MONTEFIORE-LEVI and KÜNZEL.

Cast Metal.	Diminution of Section before Rupture.	Resistance in lbs. per square inch.	
		Elastic.	Absolute.
	Per Cent.	Lbs.	Lbs.
Pure copper, ...	3·30	4·4000	6·975
Ordinary gun metal, containing 9 parts copper, 1 part tin......	3·60	12·800	16·650
Phosphor-bronze,*........	8·40	20·500	56·945
"	1·50	24·700	46·100
"	33·40	16·100	44·448
"	3·53	55·800	74·966
"	3·20	55·200	73·987
"	9·40	40·500	63·653
"	31·30	26·300	54·060
"	59·10	21·700	50·120

In the imperial arsenal at Vienna experiments were made by General VON UCHATIUS, giving the following results:—

	Absolute Resistance.	Point of Elasticity.	Stretch in Percentage.
			Per Cent.
Phosphor bronze,	5660 kilos. per sq. c.m. or 81,795 lbs. per sq. inch, ...	3800 kilos. per sq. c.m. or 54 915 lbs. per sq inch, ...	1·6
Krupp's cast steel as used for guns,	5000 kilos. per sq. c.m. or 72,258 lbs. per sq. inch,......	1000 kilos. per sq. c.m. or 14,450 lbs. per sq. inch,.....	11·0
Ordnance bronze,	2200 kilos. per sq. c.m. or 31,792 lbs. per sq. inch, ...	385 kilos. per sq. c.m. or 5562 lbs. per sq. inch, ...	15·0

It was formerly believed, and this opinion has been verified by the Berlin experiments, that both steel and iron, after being repeatedly subjected to traction, torsion, or flexion, inferior to their supposed absolute power of resistance, at last break, even at a much less strain than is due to them, most probably owing to a change of their molecular structure. These experiments have shown that the number of strains of tension, deflection, and torsion, that a metal can bear, is in the inverse ratio of the amount of force to which they have been subjected. Professor SPANGENBERG found that a bar of phosphor bronze offered an immense resistance to torsion. A bar resisted without rupture—

		Tons per sq. inch.
3,871,500	bends right and left at a strain of	14
1,996 900	" " "	15
1,590,000	" " "	16

Total, 7,458,400 bends to the right, and the same to the left.

Phosphor bronze alloys containing small percentages of phosphorus and tin are very malleable; they acquire by hammering, rolling, or drawing, great strength, toughness, and elasticity.

It was desirable to ascertain the resistance of the alloy to the chemical action of dilute sulphuric acid. For this purpose, on the 22nd of last April two similar sheets of copper and phosphor bronze were immersed in acid water of 10° Baumé strength, and at the temperature of the surrounding atmosphere. On the 28th of July it was found that the copper had lost 4·15 per cent., and the phosphor bronze only 2·3 per cent.

Phosphor bronze has been tested by Dr. KÜNZEL as to its power of resisting the action of sea water. In a comparative experiment made at Blankenberghe, lasting over a period of six months, between the best English copper and phosphor bronze, the following results were arrived at:—

Thickness of the Sheets = 0·236 Inches.	Weight before Immersion in Lbs.	Weight after Immersion in Lbs.	Loss of Weight.	
			In Lbs	PerCent.
Sheet of copper,..	74·4	72·2	2·2	3·015
Ditto ditto, ..	88·9	86·2	2·7	3·100
Sheet of phosphor bronze,..	69·5	68·75	0 75	1·123
Sheet of phosphor bronze,..	114·3	112·97	1·33	1·195

The loss in weight, therefore, due to the oxidizing action of sea water during the six months' trial, averaged for the English copper 3·058 per cent., while that of the phosphor bronze was but 1·158 per cent.

Several governments have experimented on the use of the alloy for making cannons. Without any exception, the result showed a much greater resisting power over that possessed by ordinary bronze. The following instances of the results arrived at will be of general interest.

In Belgium the ordinary bronze gun burst at the second shot, with a charge of 1 kilo. 250 grms. ($2\frac{3}{4}$ lbs.) of powder, and a cylindrical projectile weighing 8 kilos. 518 grms. ($18\frac{3}{4}$ lbs.). The phosphor bronze gun supported this charge perfectly; the normal charge was 500 grms. ($1\frac{1}{10}$th lb.) of powder, and 3 kilos. ($6\frac{3}{4}$ lbs.) of projectile.

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* The composition of the alloy was in each case the same, but the mode of preparation was modified.

In France the ordinary bronze gun burst at the second shot, with a charge of 1 kilo. 500 grms. (3½ lbs.) of powder, and 16 kilos. (35¼ lbs.) of projectile, while the phosphor bronze gun was fired five times with this charge, and burst at the second shot with 1 kilo. 750 grams. (3⅞ lbs.) of powder, and a projectile of 20 kilos. (44 lbs.), owing to the wedging of this in the barrel. The normal charge was 550 grms. (1⅜ lb.) powder and a bomb of 4 kilos. (8⅘ lbs.)

In Prussia it was shown in firing with the regulation charges, and diminishing, at each 50 shots, the exterior diameter of the chamber, that the phosphor bronze cannons only changed their dimensions when the thickness of the metal was below that of the dimensions of a cannon of the same calibre made of steel.

The Belgian government has adopted the phosphor bronze for small arms and for the harness buckles of all the cavalry.

Very satisfactory results were obtained by Major **Majendie** when testing phosphor bronze as to its liability to emit sparks when subjected to friction. The experiments were carried out in one of the workshops of the royal gunpowder mills at Waltham Abbey. A grindstone of 9 inches diameter was made to revolve very rapidly, so that any point on the grinding face would describe a distance of 2000 feet per minute; the metal was then pressed against the revolving stone, and the results proved that the harder descriptions of phosphor-bronze emit sparks less readily than the softer examples, and much less readily than ordinary gun metal or copper.

Dr. C. **Künzel** found as the results of experiments which he made on effects of friction between various substances, that the heat produced, other conditions being equal, is in proportion to the hardness of the substances; and, on the other hand, the greater the difference in the hardness of two substances rubbing against each other, the less the heat produced by the friction, and that the harder of the two heats more than the other. If friction take place between glass and cork the amount of heat received by the two respectively is as seven to one, and between bronze and cork, four to one.

For durability alone, of course, bearings should be of metal as hard as that of the arbors which they support, but considering the wear of the latter the former should be as soft as possible. In practice, however, certain precautions are to be observed; the bearing must not cut the arbor, and it must wear as little as possible; it should not get hot even when lubrication fails; and, lastly, it should possess resistance enough to bear all the shocks that fall upon it without being deformed or broken. The alloys of copper and tin generally in use are rarely homogeneous, with the exception of that which contains 82 to 83 parts of copper to 17 or 18 of tin. When there is less tin in the composition segregation takes place during cooling, which alters the homogeneousness of the alloy, and causes the cutting both of bearing and arbor. When an alloy of copper and tin sets slowly the first part consolidated is a very soft alloy, not containing more than 7 to 10 per cent. of tin; this forms, as it were, the shell of the bearing, while the hard alloy, containing 17 to 18 parts of tin, sets afterwards and fills up the pores of the shell. When a bearing thus formed is in work the soft alloy soon gives way, and the hard grains within attack the arbor, and are often torn out and carried away when grease fails.

A good bearing should be the opposite of the above. Its shell should be hard and durable, and the interior filled up with a softer composition. This result is obtained by fusing a certain proportion of phosphor bronze together with another alloy of different degree of fusibility, so as to produce by cooling two given alloys. The shell is then almost entirely formed of very tough and hard phosphor bronze, and the interior of the aforesaid soft alloy. The bearing may then be considered to consist of a series of layers of soft metal, enclosed in a casing of metal almost as hard as the arbor itself. The microscope reveals this disposition very plainly, and if one of these bearings be carefully submitted to heat, so as to cause the soft metal to run off, the rest will remain in the form of a spongy mass.

The following table shows the results obtained with various axle bearings:—

Kind of Bearing.	Composition in 100 parts Alloy.	Comparative cost of 100 Kilos. Bearings, inclusive of Melting Expenses, Loss, &c.	1 Kilo. Bearing Metal Runs.			Cost of Bearing Metal per Waggon with 4 Bearings per 100 Kilometres.	Names of Railroads where Used.
			German Miles.	Kilo-metres.	Wear per 100 Kilometres for 4 Bearings.		
		Marks.			Grammes.	S. Gr.	
Gun Metal,.......	83 copper, 17 tin,...........	$260\frac{2}{10}$	12,052	90,390	$11\frac{60}{100}$	0·301	Austrian Railway.
"	82 copper, 18 tin,...........	$260\frac{8}{10}$	13,320	99,900	$10\frac{1}{100}$	0·260	Grand Central Belge.
White Metal,......	3 copper, 90 tin, 7 antimony,	$298\frac{68}{100}$	9,104	78,280	$14\frac{64}{100}$	0·395	Austrian Railway.
"	5 copper, 85 tin, 10 antimony,	$293\frac{40}{100}$	11,750	88,145	$11\frac{35}{100}$	0·331	Niederschlesisch-Màrkische Bahn.
Phosphor bronze,..	....	350	57,226	429,200	$2\frac{33}{100}$	0·081	Grand Central Belge.

The engines of H.M.S. *Shah* failed to act satisfactorily while the crank bearings were composed of white metal, since these became so hot under the enormous strain and friction that the metal underwent partial fusion. Hence it was impossible to drive the vessel at the requisite rate through the water, and so far this otherwise splendid frigate was a practical failure. But phosphor bronze having been lately substituted for the brass and white metal, the bearings no longer run, although they may suffer some abrasion; and under the altered circumstances the *Shah* has attained her expected speed.

BELL-METAL.—The standard composition of bells is about 78 of copper and 22 parts of tin, the latter being sometimes increased to compensate for the loss by oxidation. Generally, however, the founder takes—

Copper,	77
Tin,	21
Antimony,	2
	100

Such is the composition of *cymbals* and *tam-tams*, the specific gravity of which is 8·815. Admixture of other metals, such as lead and zinc, tend to injure the quality of the tone; still, as by their use the manufacture becomes less expensive, it is customary to employ them.

The following analysis of English bell-metal by THOMSON shows the composition:—

Copper,	80·0
Tin,	10·1
Zinc,	5·6
Lead,	4·3
	100·0

Bells constituted of an alloy into which 20 to 22 per cent. of tin enter, are better and more sonorous than such as have the above composition. Besides the lead and zinc, a quantity of antimony and bismuth are sometimes introduced, in order to give a more crystalline grain to the metal, but also with the view of communicating a certain tone to the bells.

A certain requisite of bell-metal is ready fusibility, to communicate which the addition of some metals, such as those just mentioned, is made. It rarely happens that new materials are entirely used in preparing the bell-metal; old brasses and tins are worked in large quantities. The composition of these should, however, be known, so that the mean of the alloy may be such as will yield a bell of the required quality.

The moulds in which the metal is cast are constructed in much the same way as those of cannon, and the furnace employed for the fusion has also the same form, the temperature required, however, is less elevated. In the preparation of the alloy, the whole of the tin is not put in at the beginning, about one-third being reserved for addition when the whole of the bath is in perfect fusion. About one-tenth more than the weight which is destined for the bell should be submitted to the furnace, this quantity being expended in waste and scorification during the process. The tongue or clapper of the bell is usually of iron, suspended in the line of the centre of gravity, from a ring in the head, by a thong of horse leather or an iron rod. Its length ought to be such that when swung it will strike the bell near the verge, as then the sound produced is much greater than if the concussion took place further up.

The bells of clocks and those in domestic use have a somewhat larger proportion of zinc, the amount of tin being to the same extent lessened.

ESTIMATION OF COPPER IN ALLOYS.—For the sake of conciseness, it may be supposed that the alloy contains copper, zinc, nickel, tin, and lead, in order to prevent a repetition of the course to be pursued. About 30 grains of the alloy in filings, or else cut into thin slips, are introduced into a glass flask, and treated with concentrated nitric acid till the whole of the metal is decomposed. Some difficulty will attend this, unless the alloy is finely divided before subjecting it to the acid. When the whole has been oxidized, the excess of acid is to be expelled by evaporation, taking care that nothing be lost by spirting. Water must be added in sufficient abundance to dissolve the nitrates of copper, zinc, nickel, and lead from the insoluble stannic acid. Heat is applied, and after the copper is dissolved the remaining precipitate is thrown upon a filter, washed well with water to remove all traces of the accompanying salts, and afterwards dried in the water bath, ignited in the usual manner, and weighed. The filtrate from the tin, containing the nitrates of lead, zinc, nickel, and copper, is treated with sulphuric acid in excess, and evaporated till the liquid is concentrated. Sulphate of lead is thus precipitated, which must be collected upon a filter, washed, dried, ignited, and weighed. In the liquid filtered from the sulphate of lead, a precipitate of sulphide of copper is thrown down by transmitting a current of sulphuretted hydrogen through it. This precipitate is filtered and washed thoroughly, then dissolved in hot weak nitric acid and boiled to expel all traces of the gas, and then filtered. The nitrate of copper solution is precipitated by potassium hydrate, taking care that the liquor be previously diluted and raised nearly to the boiling point at the time of pouring in the alkali. The whole is further heated till the oxide of copper falls in the form of a dense black powder. This, which is the anhydrous protoxide, is filtered, and subjected to a prolonged washing with boiling distilled water, to separate the last traces of potassa. When thoroughly purified it is dried, ignited, and weighed.

The solution from the potassium sulphide is boiled to dispel all traces of the gas. Carbonate of soda is added, and a precipitate of carbonate of nickel and carbonate of zinc falls. This is collected, washed, and subsequently dissolved in hydrochloric acid, the solution evaporated, potassium hydrate added in excess, and after this hydrocyanic acid, till the precipitate which was determined is redissolved. Finally, potassium sulphide is added to this liquor to precipitate the zinc in the form of white sulphide. After removing the latter compound and washing it thoroughly, the filtrate and washings are treated with aqua regia and evaporated, to decompose the nickel potassium cyanide. Finally, by adding potassium hydrate oxide of nickel is precipitated, and after washing, drying, and igniting, is weighed.

Other courses may be pursued in the analyses of the compound metal above mentioned, but that just described will answer in general most of the purposes of the manufacturer.

Volumetric Method of Assaying Brass, Bronze, &c.—

This process, devised by E. O. Brown (Chemical Department, Woolwich Arsenal), is exceedingly accurate. 10 grains of copper are dissolved in dilute nitric acid, and the solution boiled until free from nitrous acid; it is then diluted with about an ounce of water, and carbonate of soda added until a portion of the copper is precipitated. Pure acetic acid is then added in excess, and the solution poured into a flask capable of holding about 12 ounces. About 60 grains of iodide of potassium are then thrown into the flask, and sufficient time having been allowed for the crystals to dissolve, a standard solution of hyposulphite of soda (sodium thiosulphate, $Na_2S_2O_3$) is added until the greater part of the iodine has disappeared, which is indicated by the liquid changing from a brown to a yellow colour. A clear solution of starch is then added, and the addition of the hyposulphite of soda cautiously continued until no further effect is produced. The bleaching effected by the last portions of hyposulphite of soda may be best seen by allowing the drops to fall into the centre of the flask whilst the liquid is in motion, when streaks of a lighter colour will be produced, so long as any iodine remains. The quantity of iodine employed must be at least six times the weight of the copper to be determined, and it must be free from potassium iodate. The acetic acid must contain no sulphurous acid.

The solution of starch should be made by boiling with a large quantity of water, any undissolved portions allowed to subside, and the clear liquid only used.

The solution of hyposulphite of soda is obtained by dissolving 4000 grains of the salt in 2 gallons of water. It is standardized by means of electrotyped copper by the above process.

Coloration Test.—The following process is given by Ure for the determination of small quantities of copper. This method depends on the fact that the intensity of the blue colour of an ammoniacal solution of copper is proportionate to the quantity of copper present.

1. A standard coloration test solution is prepared by dissolving a known weight of copper (0·5 or 1 grain) in dilute nitric acid, adding excess of ammonia, and diluting to 10,000 grains. This solution is kept in a well-stoppered, long, glass, graduated bottle. The ammoniacal solution of copper obtained by the decomposition of a given weight of the substance, is transferred to a graduated measure of the same shape and capacity, and water added until the tint corresponds to that of the standard coloration test. The percentage of copper is calculated as follows:—10,000 grains of the standard coloration test contains 0·5 grain copper; the solution of 100 grains of the substance required dilution to 8000 grains.

10,000 : 8000 : : 0·5 : 0·4 per cent. of copper.

2. The adaptation of this method, generally adopted in smelting works for testing slags, is as follows:—A series of standard coloration test solutions of copper are prepared and kept in a number of colourless square or round glass bottles, of exactly the same shape and capacity. If the series comprises ten bottles, the first bottle may contain $\frac{1}{10}$th of a grain of copper, the second $\frac{2}{10}$ths, and so on to the last, of 1 grain. From 50 to 100 grains of the powdered slag or other substance are treated with nitric or nitro-hydrochloric acid until decomposition is effected. In some cases previous fusion with carbonate of soda may be necessary. The solution is diluted with water, excess of ammonia added, and filtered, or the precipitate allowed to settle, and the solution decanted. If necessary, the precipitate obtained by ammonia is redissolved in acid and reprecipitated by ammonia; and if the filtrate has a blue tint, it must be added to that previously obtained. The whole of the solution is then diluted with water until there is the same volume of solution as in one of the test bottles. The colour is then compared with the coloration test bottles, and the one it corresponds to represents the amount of copper present in the quantity of substance operated on. From this datum the percentage of copper is calculated. A more rapid mode of operating is to make up the whole body of the ammoniacal solution containing the precipitate to a known volume, which is a multiple of the amount in the test bottles, and after the precipitate has settled to take a fractional part of this in a bottle of precisely the size and shape of the test bottles.

If nickel or cobalt be present the copper must first be separated by means of sulphuretted hydrogen or otherwise, and the precipitate redissolved in acid.

COPPER SALTS.—The only compounds of copper which have been prepared to any great commercial value are the acetate, sulphate, and carbonate.

Oxide of copper, CuO, chemically termed copper monoxide, cupric oxide, or black oxide of copper, has been employed to some extent as a pigment, and is known as powder blue. It is, however, an unstable colour, and consequently not much used. It may be prepared in various ways in the laboratory. If thin plates of copper be heated to low redness in the air, their surfaces become readily tarnished; a yellow colour, changing to a violet, is produced, owing to the formation of oxide of copper. Should the heat be continued and increased to redness, and then slackened, a coating of oxide of copper will be thrown off in the form of black scales. The same substance is obtained by heating nitrate of copper to redness in a crucible, nitrous acid and oxygen being evolved. Thus obtained, it is useless for the requirements of art in consequence of its colour, which is black or brownish-black. In this state it is powerfully hygroscopic, attracting moisture from the air with avidity. It requires the highest temperature of a wind furnace to fuse it, and then it parts with a certain proportion of oxygen, becoming a suboxide of the metal. Hydrogen passed over it at a red heat effects a rapid reduction, and metal results. The same change occurs when it is heated with organic substances in close vessels. When fused with vitreous matters, such as glass, it dissolves, and communicates to the mass a blue tint resembling that produced by oxide of cobalt. It was thus that the ancients, long before cobalt was known, prepared glass of a fine azure tint. The specific gravity of the black oxide of copper is 6·4. Most acids dissolve it, forming more or less blue solutions, from which potassium hydrate precipitates a bluish hydrate. Heated to the boiling point it is converted into a dark-brown powder, which is anhydrous cupric oxide, this hydrate being decomposed by heat even in presence of water. Ammonia, sparingly added, likewise throws down a similar compound, which dissolves in an excess of the reagent, forming a beautiful violet-coloured fluid. The carbonates of the fixed alkalies occasion precipitates in solution of oxide of copper; but the most characteristic is the peculiar reddish-brown which it yields with ferrocyanide of potassium. Its chemical symbol is CuO, and its atomic or equivalent weight, 79·4.

When the oxide of copper is precipitated from its solutions by potassium hydrate, it forms a blue compound of CuH_2O_2 or $CuO.H_2O$, which is used as a pigment, more especially by paper-stainers. DUMAS gives the following directions for its preparation:—Dissolve 6 parts of sulphate of copper and 3 parts of chloride of calcium, separately, in water; then mix both liquids, and after the sulphate of lime falls to the bottom, decant the liquid chloride of copper into a third vessel, where it must be well agitated with a cream made of 1½ part of lime. A greenish precipitate, consisting of a basic chloride of copper, falls, which is the crude compound sought. After collecting and washing thoroughly, it is ground with one-fourth part each of hydrate of lime and pearl ash, and put into bottles. It is customary to add a quarter of a part of chloride of ammonium, and half a part of sulphate of copper, when packing, to enable it to retain its blue colour. If left exposed, the bluish tint would disappear, and a green be substituted. Indeed, the hue changes to this, after being applied for some time, so that it is not used to any great extent.

When 5 parts of black oxide of copper and 4 parts of copper filings are heated together in a closed crucible, cuprous oxide (Cu_2O, red oxide or suboxide of copper) is formed. It is used in the glass-house to stain glass red. The colour produced is very rich.

All compounds of copper are poisonous. In some cases PEREIRA says that small doses of salts of copper give relief in diseases of the nervous system, and for this purpose have been administered under the title of *tonics*, *antispasmodics*, or *alteratives*, according to the nature of the malady; but when taken in larger quantities they occasion gastro-intestinal inflammation, and disorder the functions of the nervous system. When death ensues from these causes it is said to be produced by *acute poisoning by copper*, the symptoms of which are a cupreous taste, violent vomiting, griping pains, cramps in the legs and thighs, headache, giddiness, convulsions, and insensibility. The usual antidote for cupreous poisons is albumen or white of egg; but gluten or milk in large quantities will serve the same end. An insoluble albuminous compound of cupric oxide is formed, which must, however, be removed from the stomach immediately, otherwise the poison will ultimately, if in sufficient quantity, prove fatal.

Preparations of copper have been topically applied with considerable benefit to the patient. They act as caustics, irritants, and astringents.

Among the salts of copper the carbonate and sulphate are the only ones of which a description will be given here. For Acetate of Copper see ACETIC ACID.

CARBONATE OF COPPER.—This salt, under the title of *verditer*, is employed in considerable quantities as a pigment. The composition is not, however, a true carbonate, but a mixture of this and oxide of copper. The mineral azurite, when powdered, gives a very fine blue colour; but it is costly.

Verditer is prepared from metallic copper and its sulphate by the following process:—About 222 lbs. of copper are mixed intimately, under edge stones, with about an equal weight of common salt, the powder being afterwards made into a paste with water. 225 lbs. of thin sheet copper, cut into pieces 1 inch square, are agitated in a wooden tank or vessel with 2 or 3 lbs. of strong sulphuric acid, diluted with water, to remove any coatings of oxide or other impurities which might prevent the oxidation of the metal in a subsequent operation. As soon as the acid has acted sufficiently upon the surface it is decanted, and the fragments introduced into barrels, which are made to rotate on their axes, and thoroughly washed with water. Afterwards the bits of metal are mixed with the saline paste already mentioned, and deposited in layers in the bottom of what is called the oxidation chest. Here the metal, through the agency of the salts which absorb oxygen, becomes oxidized in proportion to the extent of surface in contact with the air. In order, therefore, that the transformation may be as perfect as possible, the layers should not be over thick; and they ought to be turned over once a week to present a fresh surface to the atmosphere. This is done by turning the contents of the chest into an empty one, and transferring the matter back into the former again. At the close of three months the process of oxidation comes to an end. The mass is now turned over, and particles of metal which might still remain are carefully picked out. The residue is washed with the smallest quantity of water to separate the saline matter, and then filtered. The magma (*schlam*) remaining on the filter is next transferred in buckets which hold about 30 lbs. into a large tub, and for every 6 measures introduced 12 lbs. of hydrochloric acid, of specific gravity 1·109, are added. The whole is then well commingled and left at rest for thirty-six or forty-eight hours. The effect of this is to produce a soluble chloride of copper, from which the oxide is to be thrown down afterwards by a solution of an alkali. This is prepared in the usual way with caustic lime, and the proportion used is 15 measures—specific gravity being 1·142—to every 6 pailfuls of the acidified precipitate already mentioned. After the usual time for standing has elapsed the mixture is transferred quickly into the tank containing the alkali, and the whole briskly stirred till it becomes rather consistent, when it is left to repose for thirty-six to forty-eight hours. The precipitate by this time will have subsided. The supernatant fluid is siphoned, and the blue precipitate repeatedly washed with water, and, after the settling of the solid matter, decanted.

When all traces of alkalinity have been removed the precipitate is thrown into filter-bags, where it is freely exposed and repeatedly moistened, and finally allowed to drain. After this the matter is cut into small pieces and exposed to spontaneous dessication in the air till it becomes thoroughly dry. The latter may be conducted in a chamber, but the temperature should not exceed 78° Fahr.

If the several operations be properly conducted, and the final exsiccation thoroughly performed, a beautiful product results; but the smallest amount of moisture, if retained, tends to injure the colour, on which the value of the substance almost entirely depends.

Another variety of the same may be obtained by agitating chalk with a solution of nitrate of copper for some time; double decomposition takes place, and carbonate of copper precipitates. When it has completely subsided the solution of nitrate of lime is decanted, and fresh additions of water made after each decantation till the residue is sufficiently purified. The colour of the precipitate when dried is greenish, but the blue shade is communicated by mixing with it 8 or 10 per cent. of fresh-burnt lime. If this addition be made while the compound is in the pasty state, and the whole well triturated for some time, a uniform hue is produced.

An inferior kind of verditer is prepared by mixing subsulphate of copper and chalk together, and washing as above described.

The composition of this body varies with the nature of the course followed in its manufacture; but a good article approaches to the annexed results of the analyses of samples of verditer:—

	Theory.	Berzelius.	Proust.
Oxide of copper,	72·07	71·70	69·5
Carbonic acid,	19·82	19·73	25·0
Water,	8·11	8·57	5·5
	100·00	100·00	100·0

Verditer is employed to a large extent in the manufacture of paints, and as a substitute for verdigris.

SULPHATE OF COPPER.—*Roman vitriol*, *Blue vitriol*, *Blue stone*, *Cupric sulphate* ($CuSO_4,5H_2O$).—This is the most important of the salts of copper, and the one which is manufactured in largest quantities. Many ways are known for preparing it in the laboratory—such as exposing pure copper in thin sheets to the joint action of dilute sulphuric acid and air; treating freshly precipitated oxide of copper with diluted sulphuric acid, or boiling the metal with either concentrated sulphuric acid, or the acid diluted with an equal bulk of water. In all three a solution of sulphate of copper is obtained, from which the salt may be removed in well-defined rhomboidal crystals of a fine sapphire blue colour. They are liable to effloresce when exposed to the air, owing to the escape of water of crystallization. Four parts of cold and two parts of boiling water are required for their solution. In crystallizing, sulphate of copper takes up five equivalents of water, of which four may be expelled at 212° Fahr., but the expulsion of the last requires a temperature of 400° Fahr. Deprived of moisture, the salt is white; in this state, on account of its hygroscopic properties, it is employed as a test for determining the presence of water in some spirituous liquids, such as alcohol, &c.; when exposed to moist air, or to contact with aqueous liquids, it re-assumes its usual bluish colour. At a very high temperature sulphuric together with sulphurous acid and oxygen are expelled, and cupric oxide is left. When heated in close vessels with an excess of charcoal, reduction takes place, sulphurous and carbonic acids are evolved, and metallic copper remains. Sulphate of copper is decomposed by hydrochloric acid, chloride of copper being formed and sulphuric acid set free. Anhydrous sulphate of copper is represented as $CuSO_4$.

Besides the above methods, many others are followed. Already, when describing the manufacture of copper from its ores, occasion has offered of showing that, by calcining the pyritous minerals in contact with air, the sulphur and copper are oxidized, so as to give rise to a sulphate of the metal; this is more especially the case if nitrate, or any other oxidizing substance, be heated with the mineral, for then nearly the whole of the sulphur will be converted into sulphuric acid, which unites itself with the oxide and forms the substance. For extracting it, the roasted ore is thrown into a tank, and a moderate amount of water added, and left to digest for some time, during which those portions of the ore that were unaffected in the furnace now undergo oxidation, and produce sulphate of copper. The liquor after being drawn off is evaporated to the crystallizing point, and the residue left in the first tank, if not entirely exhausted of its copper, is subjected to a second roasting with a fresh quantity of ore, and exhausted with water as in the preceding instance.

A very small proportion only of the sulphate of copper manufactured is obtained by the above process, the chief bulk being prepared by acting upon the scales which are separated from the metal when undergoing the process of lamination; the dipping liquor of the coppersmith is also used for the same purpose. The details of the manufacture are very simple:—A stout wooden vessel lined with lead is provided, and into this a certain quantity of copper scales and strong sulphuric acid is introduced; both are agitated, and the whole left till the solution becomes saturated with the sulphate of copper. To assist the action of the acid, steam is blown through a lead pipe passing nearly to the bottom of the tank. When the acid becomes saturated, the liquor is drawn off into other leaden vessels, arranged in a warm room, and allowed to crystallize. In the course of five or six days a crop will be obtained; the mother-lye is decanted and added to fresh liquor that is ready for crystallization. After draining, the crystals are dried and packed for sale; sometimes they are packed when merely drained of their moisture. In this operation all the scales are not dissolved—only such portions as have undergone thorough oxidation. The residuary matter remaining in the tank after the action of the acid has ceased is washed with water, dried, and sent to the furnace with blister copper to be refined.

The following examples will serve to illustrate the process on the large scale. 5 cwts. 2 qrs. by weight of copper scales were treated with 685 lbs. of sulphuric acid of 1·700 density, water being added in sufficient quantity, and the produce was 5 cwts. 2 qrs. 24 lbs. of crystals of sulphate, together with 122 galls. of mother-liquor of 1·180 spec. grav., and 160 galls. of 1·100 density. By operating upon a portion of those liquors, it was found that the total weight of the sulphate of copper produced was equal to 1240 lbs., and that for their production only 350 lbs. of the scales were taken up.

In another instance, 7 cwts. of the scales were taken, and 800 lbs. of strong sulphuric acid of specific gravity 1·700 added to them, together with a sufficient quantity of water; 7 cwts. 1 qr. 14 lbs. weight of crystallized sulphate of copper were obtained, together with 138 galls. of mother-liquor of a specific gravity of 1·176, and 116 galls. of 1·080 gravity, both together holding 825 lbs. of the salt in solution, so that the total quantity was 1651 lbs. of salt, leaving 2 cwts. 3 qrs. 18 lbs. of the scales unacted upon.

The dipping liquor of the brazier is also used as a source of sulphate of copper; but the product which it affords is not of good quality, owing to brasses and other alloys being subjected to the action of the acid, and of course sulphates of zinc, iron, and other bases being present as impurities. Occasionally, this *pickle* is added to the cupreous liquor obtained by acting upon the scales with vitriol, and the whole crystallized; the product, although serviceable in some cases, cannot, however, be used in place of pure salt.

Considerable quantities of sulphate of copper are employed in the preparation of other compounds, such as verditer, acetate of copper, *Scheele's green*, &c. It has likewise been found serviceable in agriculture for the purpose of steeping the seeds, in order, as is said, to prevent thereby the ravages of insects, the smut and other analogous blights in the crop; but the inferior kinds are taken for this purpose. It has also been employed to saturate wood or timber as a preventive against the dry rot. It is also very largely employed as a base for several of the green and blue colours applied in calico printing.

The method of analysis which is followed in determining the value of the salts of copper is similar to that described for the estimation of copper in ores or alloys of the metal.

The sulphate of copper of commerce is often contaminated with sulphate of iron, zinc, or magnesium.

If the presence of iron alone be suspected, dissolve the crystals in water, boil for some time with nitric acid, and then add excess of ammonia. The ammonia precipitates at first both the iron and the copper, but the latter speedily redissolves, whilst the ferric oxide is left as insoluble reddish brown flakes.

If the sulphates of zinc and magnesium are likewise present, dissolve a weighed quantity of the salt in water, acidify strongly with hydrochloric acid, and pass a current of sulphuretted hydrogen slowly through the acid solution until it smells strongly of the gas. A black precipitate of copper sulphide is produced; filter rapidly, and wash with sulphuretted hydrogen water. The sulphide of copper is then dried, and treated in a beaker with nitric acid until the sulphur is separated. The solution is then filtered, and the cupric oxide precipitated with potassium hydrate; after boiling the precipitate is collected, dried, and ignited.

The liquor filtered from the sulphide of copper is heated till all smell of sulphuretted hydrogen ceases, nitric acid is then poured on it, and the whole boiled to convert the iron into ferric oxide; the acid liquor is then neutralized with ammonia, and precipitated by succinate of ammonium. The liquor filtered off is then heated with ammonium sulphide, which, if zinc be present, will produce white precipitate. The liquor from the zinc sulphide is then supersaturated with hydrochloric acid to decompose the ammonium sulphide, and the magnesia, if any, precipitated as bibasic phosphate of ammonium and magnesium by means of a solution of sodium phosphate and ammonia.

DISINFECTANTS.—*Desinfectants*, French; *desinficirungs-mitteln*, German; *disinfettanti*, Italian.—The word "disinfectant," in its full and general sense, means a substance that will remove, neutralise, or destroy that which is noxious to animal life. Antiseptics, or those substances which prevent the organic matter with which they are placed in contact from entering into a state of putrefaction, are also to that extent disinfectants. The burning of bedding, &c., when its object is to destroy contagion, is disinfection, since the hurtful organic matter is thus destroyed by fire.

Disinfectants may be divided into—volatile, in the form of gas or vapour; and solid or liquid.

Volatile Disinfectants.—1. Substances which, like the halogens, appear to form substitution compounds—*e.g.*, chlorine, bromine, iodine.

2. Substances which probably combine chemically, and thus destroy contagion:—Sulphurous acid, nitrous acid, fumes of other acids.

3. Oxidizing substances, such as pure air, oxygen, ozone.

4. The volatile oils, &c., feeble disinfectants, supposed, however, to oxidize—Camphor, the oil of hops, rue, rosemary, chamomile, &c.

Liquid and Solid Disinfectants and Disinfecting Agencies.—1. All soluble chlorides, particularly those of the alkaline metals:—Calcium, iron, copper, manganese, zinc, aluminium, mercury, &c.

2. All soluble sulphates, especially sulphates of iron and aluminium.

3. All soluble sulphites.

4. Some acetates, as acetate of iron.

5. Some nitrates, as nitrates of potassium and sodium.

6. Certain agents which appear to arrest putrefaction, or condense certain gases without either destruction or oxidation: — Carbolic acid, salicylic acid, tar acids, charcoal, great cold, heat sufficient to dry organic substances, but not to char them.

7. Preservative liquids and solutions. Many of these act by coagulating the albumen of organized bodies. Antiseptics, alcohol, solutions of corrosive sublimate, common salt, and saltpetre.

8. Destructive agents. Not true disinfectants; they act not by disinfection, but by destruction :— A dry heat of 200° to 400° Fahr.; strong acids and strong alkaline solutions.

9. Agents which act in many ways, partly by absorbing moisture, partly by condensing gases, and partly by a peculiar action on organic matter analogous to tanning. These are:—Dry earths, clays, and the natural and artificial compounds of aluminium. —(BLYTH, *Dict. of Hygiène*).

The ancients seem to have attained the knowledge of antiseptics at a very early period—their first attention being directed to the disposal of the dead in such a fashion that the body should cease to be hurtful or annoying to the living. This was doubtless the primary idea of disinfection. In embalming the body, after the removal of the viscera, was washed with palm oil and aromatic substances, and was then filled up with powdered myrrh, cassia, and other perfumes; after this it was buried in *natron* (soda) for seventy days, and, finally, was protected from atmospheric action by being enveloped in gummed cloth. Or, for a cheaper process, the intestines were filled with what HERODOTUS termed *cedar oil* (turpentine) and the body salted; the former having consumed the flesh, leaving only the skin and bones, was then removed. At other times, it is stated, the corpse was merely treated with a cleansing wash, and then *steeped* in soda. Others, and the greater part of the Egyptian mummies, were treated with asphalt only, converting the body into one black mass.

The burning of bodies was another mode of disposing of animal matter liable to decomposition. The ashes were generally deposited in urns; hence the little niches like pigeon-holes, forming the *columbaria* of the Romans, for the reception of such vessels.

As organic substances which are deprived of their water do not decompose, drying was also adopted at an early period, both amongst the Egyptians and in other countries, as a means of stopping eremacausis, *i.e.*, the slow oxidation of organized structures; and there can be little doubt that this formed a part of every process of embalming. The preservation of these bodies is due to the dryness of the receptacles, as well as to the art of the embalmer.

Washing with pure water to remove all putrescent or putrescible matters has always been, and must continue to be, the most important disinfectant, whenever it can be applied. Hence came the purification of early times. This was undertaken whenever anything noisome, especially a dead body, had been touched. The Mosaic command on such occasions is to wash the clothes of the infected person, and set him apart as unclean until the morning, or longer according to circumstances; thus ablution is considered insufficient — time also is needed. This is not a mere symbolical or moral impurity demanding time, even after the cleansing, without a physical cause; it is also a kind of quarantine, established in private, perhaps useful, and at least incapable of doing injury. The disinfection of houses was the work of the Jewish priests.

The soil is a very valuable disinfectant, decomposing animal matter with great rapidity, the gases given off being, when sufficient space has been allowed for the remains, absolutely innocuous.

Efficacious as the soil is for the absorption and gradual destruction of bodies buried in it, it has been found in large towns that the amount of soil covering the dead has been insufficient; most nations, therefore, have interred their dead in the suburbs and less populous localities.

During the last few years the process of burning the dead has been advocated, and cremation has been carried out, though on a very limited scale, in some continental towns—the dead body being placed in a furnace specially constructed for the purpose, and completely calcined and reduced to ashes.

Embalming has been resorted to in Europe from the very earliest times, and with great success. The remains of the French kings disinterred in St. Denis by the revolutionists preserved their countenances, it is said, perfectly when first uncovered; but immediately disintegrated when exposed to air. Abundant instances are found in history of similar preservation, although the particulars of the processes adopted in the middle ages are even less known than the Egyptian methods, while, at the same time, they appear to have been more successful. Sometimes the preservation is effected by the mere action of a constant current of air. This may be readily believed of a warm climate; but the same result occurs at Bonn, in the vault of a chapel, where the bodies of the monks are dried up and shrivelled, but not decomposed. No means whatever, it is said, are used to obtain this result, further than placing an open coffin containing the body in a dry repository through which the wind is continually blowing.

Out of the original idea of purification and disinfection many ceremonies have arisen; such, in all probability, are *lustrations*, and all those in which incense is used. When ULYSSES burnt sulphur to remove the infection emanating from the dead bodies of the suitors, he retained the original rite, which had not lost its meaning in mere antics. When the Roman shepherds burnt sulphur and herbs once a year, sacrificing to PALES, and adorning their folds with wreaths, part of the original process of disinfection was retained, though it was rapidly degenerating into mummery. The perfumed oils put on the bodies of the dead were more for the concealment of the effluvia than for any powerful disinfectant quality which they possessed.

Closely connected with the decomposition of animal matter is fermentation; and it has been of late years thoroughly established that bodies or circumstances which prevent the one interrupt the other. In the manufacture of wine, fermentation may be checked by the use of some oils, such as turpentine, as well as acids, especially carbolic, sulphurous, &c. When fermentation of grape juice is completed, oxidation and the formation of acetic acid commence, or complete decay sets in. To prevent this the ancients employed agents of various kinds—sea-water, turpentine or resins, caustic lime (either from common limestone, marble, or shells), gypsum, aromatic herbs and spices, gums, &c. The vessels were also sometimes lined with pitch, and occasionally powdered pitch was thrown into the fermenting juices. Besides these were used almonds, raisins steeped in must, parched salt, goats' milk, cedar cones, gall-nuts, and blazing pine-torches, or red-hot irons quenched in the liquid. Salts of lead were also in request, either to alter the taste or to prevent decomposition, and remove impure matter and clarify the wine. In some places aloes were employed, producing a slight bitter, like that of the well-hopped Burton ale of the present day; in others the flavour—as in the Scotch and Irish whisky—was given by smoke.

Although the ancients do not appear to have had very accurate knowledge as to the conditions requisite for the decomposition of organic matter generally, they proved their knowledge of the necessity of preventing the emanations of marshes by drying them up; of shutting out certain winds, by completely stopping all the crevices on the exposed side of their houses; whilst they also fused aromatic herbs and kindled fires in the streets in time of plague.

CAUSES OF INFECTION.—Infection arises from germinating matter, which, coming in contact with that which is healthy or sound, but contains the constituents necessary for carrying on its growth, induces a continuation of the decay.

Animal and vegetable matters were formerly supposed to decompose spontaneously; but it is now known that in no case can either putrefaction or infection occur without the presence of *living germs.*

Diseases may be propagated, be it granted, by contact with infected persons, but to one common source all must in the first instance be due, viz., to the presence of infectious matter, *i.e.*, matter capable of propagating disease.

There is much dispute as to the origin of various diseases, and also as to the nature and manner of their infection; in treating of disinfection we must only aim at what can be undoubtedly accomplished, viz., the method of preventing or destroying what is noxious or contagious rather than considering whether each distinct kind of decomposition and each specific form of infectious disease are the results of vital manifestation of special germs differing in each case, or whether they are caused by the molecular movements of organic matter in peculiar states of decay.

When a country is badly drained, and there is no outlet for the products of the decomposition of plants but the air, it often happens that disease spreads rapidly. If the land be properly drained, these emanations passing through the soil become disinfected, and a comparatively healthy atmosphere results. Marshes in all ages have been unwholesome; but they are so in proportion to the temperature and the state of vegetation. A damp climate and a moist soil, such as those of Holland, do not produce disease in an equal degree with a similar condition in the tropics, where decay is more accelerated.

Ponds, and such collections of water which are too shallow to prevent rapid decomposition, and allow the sun's rays to enter so as to encourage the growth of plants at the bottom, become fertile sources of disease. They can only be disinfected entirely by destruction of the vegetation.

Masses of matter in a state of decomposition around a dwelling may easily become centres of contagion; and the best method of dealing with these is to remove them immediately; but if in a dangerous condition, to disinfect them previously, as their removal without previous disinfection abundantly disseminates the noxious matter.

A still atmosphere induces the spread of infection, as a whole district or country may become like a closed vessel, rapidly filling up with impure matters, and pestilence being consequently generated. Hurricanes, it is well known, have a powerful tendency to stop the progress of disease (probably by chilling the germs and rendering them inactive).

Air is the great vehicle for conveying organic matter, and indeed it would be difficult to imagine a state of the atmosphere in which organic matter did not exist, and the recent researches of Dr. ANGUS SMITH on air, collected in various rooms and crowded places, prove to us the immense importance of good ventilation. Even the air which has been breathed by healthy persons is found to be injurious if allowed to collect; but when emanating from those with unhealthy constitutions, it communicates disease very readily. Its first action is on the nasal organ, where its nature generally gives notice of contiguous evil; but when persons are accustomed to living in impure air, habit causes them to be insensible to its effects. It next enters the lungs, where the blood absorbs it; distemper is thereby communicated to the most vital parts in a direct manner.

Dust and Germ Laden Air.—In the year 1868 Professor TYNDALL communicated to the Royal Society the results of his investigations on chemical reactions produced by light. In these researches the vapours of volatile liquids were subjected to the action of concentrated sunlight, or to the concentrated beam of the electric light.

The apparatus employed in these experiments consisted of an experimental glass tube, about 3 feet long and 3 inches in diameter. Its ends were stopped by plates of glass. The tube was connected with an air-pump and exhausted of air. Purified air was then allowed to bubble slowly through a certain volatile liquid, contained in a flask, and when charged with the vapour of this liquid to pass into the experimental glass tube. A powerfully converged beam from the electric light was then passed into the tube, and the vapour therein contained being decomposed by the action of the beam, was precipitated in myriads of fine particles.

In all cases where the amount of vapour in the experimental tube was large, the decomposing action was very rapid, and the particles constituting the precipitated cloud were so large in size as to whiten the luminous beam. If, however, the vapour in the experimental tube was in a highly attenuated condition, the decomposing action of the beam was very slow, and the cloud particles when first precipitated were infinitesimal in size. Thus, purified air, charged with the vapour of the liquid nitrite of amyl, was passed into the exhausted experimental tube until it was completely filled. A convergent beam from the electric light was then sent into the tube. For a moment the tube was optically empty, nothing whatever was to be seen within it; but before a second had elapsed decomposition took place, and a dense cloud of particles almost instantaneously was precipitated upon the beam. So rapid and intense was this precipitation, that the convergent cone of light which a moment before was invisible flashed suddenly forth like a solid luminous spear. In an exceedingly short time the tube was filled with a dense cloud, which reflected brilliantly the luminous beam.

The experimental tube was then charged with the vapour of the liquid nitrite of amyl in a highly attenuated condition. The convergent beam of light was passed into the tube as before, but it required some minutes' exposure to the decomposing beam before the action became manifest. Decomposition then commenced, and advanced slowly, the cloud particles precipitated being almost infinitesimal in size. The cloud thus formed presented the most delicate appearance, and reflected a deep and rich blue light, equalling the finest blue of the sky.

In this manner a large number of vapours were submitted to the action of light and decomposed. Various gases were used instead of air as the vehicle for carrying the vapour, proving the decomposition to take place in the vapour alone, and not to any interaction between the vapour and its vehicle. The heat rays and the chemical rays were separated, and the vapour submitted to the action of each proved the power of decomposition to be due to the latter and not to the former. With a proper mixture of vapours in an attenuated condition, gorgeous blue clouds were produced, which exhibited all the phenomena of polarization obtainable from the light of the sky.

The ordinary air of the laboratory in which these investigations were conducted, although invisible in diffuse daylight, was found loaded with floating dust when illuminated by a powerful beam of light. During the early part of the investigation Professor TYNDALL was much troubled by the appearance of this floating dust in his experimental tube. For no matter what precautions were taken as to its cleanliness, or with what care and slowness the vapour-laden air was admitted, these floating dust particles were invariably present, the condensed beam of light passed into the tube instantly revealing them.

It was of importance, therefore, especially when the decomposing action was slow and the precipitated cloud very delicate in texture, that the space containing the vapours should embrace no visible thing; that no substance capable of scattering the light in the slightest degree should at the outset be found in the experimental tube.

With a view to the removal of this floating matter from the air, the following series of experiments was made :—

Before the air entered the flask containing the liquid whose vapour was to be examined, it was thoroughly dried and its carbonic acid removed by passing it in succession through two tubes; one of them containing fragments of glass wetted with concentrated sulphuric acid, the other fragments of marble wetted with a strong solution of caustic potash. But although the acid will destroy all the floating matter of the air when left sufficiently long in contact with it, it is incompetent to do so when the air is carried over it, even with exceeding slowness. The aspect was substantially the same when the air was permitted to bubble through the liquid acid and through the solution of potash. The core of the bubble does not touch the acid, and even the dust particles which come into contact with the acid require time to be wetted by it.

Thus, successive charges of air were admitted through the potash and sulphuric acid into the exhausted experimental tube. Prior to the admission of air the tube was optically empty; it contained nothing competent to scatter the light. After the air had entered the tube the conical track of the electric beam was in all cases clearly revealed.

After trying the interception of the floating matter in various ways, the air immediately before entering through the drying apparatus into the exhausted experimental tube was permitted to pass over the top of a spirit lamp flame. The floating matter no longer appeared, having been burnt up by the flame. It was therefore of organic origin, for if it had been inorganic it would have been incombustible.

In place of the drying apparatus a small platinum tube which could be heated to vivid redness was connected with the experimental tube. The tube also contained a roll of platinum gauze, which, while it permitted the air to pass through it, insured the practical contact of the dust with the incandescent metal. The air of the laboratory was permitted to enter the experimental tube, sometimes through the cold and sometimes through the heated tube of platinum. The rapidity of admission was also varied. In the first column of the following table the quantity of air operated on is expressed by the number of inches which the mercury gauge of the air-pump sank when the air entered. In the second column the condition of the platinum tube is mentioned, and in the third the state of the air which entered the experimental tube.

Quantity of Air.	State of Platinum Tube.	State of Experimental Tube.
15 inches ..	Cold ..	Full of particles.
15 " ..	Red-hot ..	Optically empty.

The phrase "optically empty" shows that when the conditions of perfect combustion were present the floating matter totally disappeared. It was wholly burnt up, leaving no sensible residue. The experiment was repeated many times with the same invariable result.

In a cylindrical beam, which powerfully illuminated the dust of the laboratory, was placed an ignited spirit lamp. Mingling with the flame and round its rim were seen wreaths of darkness resembling an intensely black smoke. On lowering the flame below the beam the same dark masses stormed upwards. They were at times blacker than the blackest smoke from the funnel of a steamer; and their resemblance to smoke was so perfect as to lead the most practised observer to conclude that the apparently pure flame of the alcohol lamp required but a beam of sufficient intensity to reveal its clouds of liberated carbon.

But is the blackness smoke? This question presented itself in a moment. A red-hot poker was placed underneath the beam, and from it the black wreaths also ascended. A large hydrogen flame was next employed, and it produced those whirling masses of darkness far more copiously than either the spirit flame or poker. Smoke was therefore out of the question.

What then was the blackness? It was simply that of stellar space; that is to say, blackness resulting from the absence from the track of the beam of all matter competent to scatter its light. When the flame was placed below the beam the floating matter was destroyed *in situ*; and the air, freed from this matter, rose into the beam, jostled aside the illuminated particles, and substituted for their light the darkness due to its own perfect transparency. Nothing could more forcibly illustrate the invisibility of the agent which renders all things visible. The beam crossed, unseen, the black chasm formed by the transparent air, while at both sides of the gap the thick-strewn particles shone out like a luminous solid under the powerful illumination.

Oxygen, hydrogen, nitrogen, carbonic acid, so prepared as to exclude all floating particles, produce the darkness when poured or blown into the beam. Coal gas does the same. An ordinary glass shade placed in the air with its mouth downwards permits the track of the beam to be seen crossing it. Let coal gas or hydrogen enter the shade by a tube reaching to its top, the gas gradually fills the shade from the top downwards. As soon as it occupies the space crossed by the beam the luminous track is instantly abolished. Lifting the shade so as to bring the common boundary of the gas and air above the beam the track flashes forth. After the shade is full, if it be inverted the gas passes upwards like a black smoke among the illuminated particles.

If the nozzle of an ordinary pair of bellows be filled with cotton wool, not too tightly packed, the air urged through the wool is filtered of its floating matter, and it then forms a clean band of darkness in the illuminated dust.

A large and compact mass of cotton wool tied around the entry of the experimental tube was found competent to hold back the floating matter. A glass tube of small bore, plugged with cotton wool in the same manner as the nozzle of the bellows, proved to be a perfect filter of the dust-laden air. Being convenient in application and form, it was adopted and used as the dust filter throughout the investigations on the chemical reactions produced by light.

The above experiments, though at first looked upon by practical men as interesting only from a scientific point of view, have since borne much fruit, and have cleared the way for a complete conception of the relations of the floating matter in the air to the various phenomena of putrefaction and infection. Dr. TYNDALL had this end fully in his mind, for in a discourse on the subject he proceeds:—

"But what, you may ask, is the practical good of these curiosities? And if you so ask, my object is in some senses gained, for I intended to provoke this question. I confess that if we exclude the interest attached to the observation of new facts, and the enhancement of that interest through the knowledge that by-and-by the facts will become the exponents of laws, these curiosities are in themselves worth nothing. They will not enable us to add to our stock of food, or drink, or clothes, or jewellery. But though thus shorn of all usefulness in themselves, they may, by leading the mind into places which it would not otherwise have entered, become the antecedents of practical consequences. In looking, for example, at this illuminated dust, we may ask ourselves what it is. How does it act, not upon a beam of light, but upon our own lungs and stomachs? The question at once assumes a practical character. We find on examination that this dust is organic matter—in part living, in part dead. There are among it particles of ground straw, torn rags, smoke, the pollen of flowers, the spores of fungi, and the germs of other things.

"The air of our London rooms is loaded with this organic dust, nor is the country air free from its pollution. However ordinary daylight may permit it to disguise itself, a sufficiently powerful beam causes the air in which the dust is suspended to appear as a semi-solid rather than as a gas. Nobody could, in the first instance, without repugnance place the mouth at the illuminated focus of the electric beam and inhale the dirt revealed there. Nor is the disgust abolished by the reflection that, although we do not see the nastiness, we are churning it in our lungs every hour and minute of our lives. There is no respite to this contact with dirt; and the wonder is, not that we should from time to time suffer from its presence, but that so small a portion of it would appear to be deadly to man."

And what is this portion? It was some time ago the current belief that epidemic diseases generally were propagated by a kind of malaria, which consisted of organic matter in a state of *motor-decay;* that when such matter was taken into the body through the lungs or skin, it had the power of spreading there the destroying process which had attacked itself. Such a spreading power was visibly exerted in the case of yeast. A little leaven was seen to leaven the whole lump, a mere speck of matter in this supposed state of decomposition being apparently competent to propagate indefinitely its own decay. Why should not a bit of rotten malaria work in a similar manner within the human frame? In 1836 a very wonderful reply was given to this question. In that year CAGNIARD DE LA TOUR discovered the *yeast plant*, a living organism, which when placed in a proper medium feeds, grows, and reproduces itself, and in this way carries on the process which we name fermentation. Fermentation was thus proved to be a product of life instead of a process of decay.

SCHWANN, of Berlin, discovered the yeast plant independently; and in February, 1837, he also announced the important result, that when a decoction of meat is effectually screened from ordinary air, and supplied solely with calcined air, putrefaction never sets in. Putrefaction, therefore, he affirmed to be caused by something derived from the air, which something could be destroyed by a sufficiently high temperature. The experiments of SCHWANN were repeated and confirmed by HELMHOLTZ, URE, and PASTEUR. But as regards fermentation, the minds of chemists, influenced probably by the great authority of GAY-LUSSAC, who ascribed putrefaction to the action of oxygen, fell back upon the old notion of matter in a state of decay. It was not the living yeast plant, but the dead or dying parts of it, which, assailed by oxygen, produced the fermentation. This notion was finally exploded by PASTEUR. He proved that the so-called "ferments" are not such; that the true ferments are organized beings which find in the reputed ferments their necessary food.

In a recent communication to the Royal Society, on the optical condition of the atmosphere in its bearings on putrefaction and infection, Professor TYNDALL has shown that organic infusions of all kinds, when properly prepared, may be exposed to ordinary air for any length of time, and yet be preserved pure and free from putrefaction, the only condition necessary being the removal of the floating matter.

For this purpose a number of cases or chambers were constructed, each with a glass front, its top, bottom, back, and sides being of wood. At the back a little door is constructed to open and close on hinges, while into the sides are inserted two panes of glass facing each other. The top of the case is perforated by two apertures, into which is inserted air-tight two narrow glass tubes, intended to connect the interior space with the atmosphere. The tubes are bent several times up and down so as to intercept and retain the particles carried by such feeble currents as changes of temperature might cause to set in between the outer and inner air.

Into one or more rows of holes, pierced in the bottom of the case, is fixed air-tight large test tubes, intended to contain the liquid to be exposed to the action of the moteless air. The tubes thus inserted in a single case varied from three to twelve in number.

The interior of the case was coated with glycerine, and every part closed air-tight excepting the ends of the bent glass tubes. A powerful concentrated beam of light passed into the case through the side window showed the air within to be laden with floating matter. The case was then allowed to remain perfectly quiet for three days, when it was again examined by the concentrated beam, and was found to be optically empty. Thus three days of quietude had sufficed to cause all the floating matter to be deposited on the top, sides, and bottom of the case, where it was held fast by the coating of glycerine.

A strong and clear organic infusion was then introduced (through a pipette inserted air-tight through the top of the case) into the test tubes, and boiled for five minutes in a bath of oil. They were then abandoned to the action of the moteless air, maintained at a temperature of from 60° to 80° Fahr.; at the same time the same infusion, placed in similar test tubes, and boiled for five minutes in the oil bath, were exposed to the ordinary mote-laden air of the laboratory, kept at the same temperature as that in the closed case. After two or three days all the infusions exposed to the ordinary mote-laden air had fallen into a state of putrefaction, were very turbid, and swarming with life; while the infusion exposed in the closed case to the action of the moteless air, remained as pure and clear as the day it was introduced. In this pure and clear condition the infusion remained for a period of nearly five months, when the door at the back of the case was opened, and the mote-laden air being thus admitted, sufficed in three days to render the infusion turbid with putrefaction and rottenness.

In this manner infusions of a number of animal and vegetable substances, consisting of hay, turnips, tea, coffee, hops, malt, beef, mutton, pork, hare, rabbit, kidney, liver, fowl, pheasant, grouse, haddock, sole, mullet, salmon, cod, turbot, herring, whiting, eel, oysters, urine, &c., have been subjected to the action of air cleansed of its floating matter by self-subsidence, for a lengthened period of time. In every case the infusions have remained perfectly clear and unaffected, while the same infusion exposed to air containing the floating matter, were invariably smitten with putrefaction in two or three days.

In a similar manner various infusions have been exposed to the action of air freed of its floating matter by filtration through cotton wool, to air cleansed by its passage through the red-hot platinum tube, and to a vacuum; and in every case they have remained perfectly clear and unaffected.

The sole condition necessary to cause these long dormant infusions to swarm with active life, is the access of the floating matter of the air. After having remained for months as pellucid as distilled water, the opening of the back door of the protecting cases, and the consequent admission of the floating matter, in three days rendered the infusions putrid and full of life.

Infusions of various kinds contained in 139 glass flasks, with necks drawn out and narrowed, were boiled for five minutes and hermetically sealed while boiling. The infusions thus prepared retain to this hour the clearness and colour which they showed on the day they were boiled, while specimens exposed to the laboratory air have long ago fallen into utter rottenness.

Experiments were conducted with regard to the distribution of the germs in the atmosphere. A tray of 100 tubes, containing hay, turnip, and beef, were exposed to the ordinary air, and from the irregular manner in which the tubes were infected, it may be inferred, that as regards quantity the distribution of the germs in the air is not uniform, but that they float through the air in groups or clouds, with space more sparsely filled between them.

Side by side with these researches and discoveries, and fortified by them and others, has run the *germ theory* of epidemic disease. The notion was expressed by Kircher, and favoured by Linnæus, that epidemic diseases are due to germs which float in the atmosphere, enter the body, and produce disturbance by the development within the body of parasitic life. The strength of this theory consists in the perfect parallelism of the phenomena of contagious disease with those of life. As a planted acorn gives birth to an oak competent to produce a whole crop of acorns, each gifted with the power of reproducing its parent tree; and as thus from a single seedling a whole forest may spring: so, it is urged, these epidemic diseases literally plant their seeds, grow, and shake abroad new germs, which, meeting in the human body their proper food and temperature, finally take possession of whole populations. Thus Asiatic cholera, beginning in a small way in the Delta of the Ganges, contrived in seventeen years to spread itself over nearly the whole habitable world. The development from an infinitesimal speck of the virus of small-pox of a crop of pustules, each charged with the original poison, is another illustration. The reappearance of the scourge, as in the cases of the *Dreadnought* at Greenwich, reported on so ably by Dr. Budd and Mr. Busk, received a satisfactory explanation from the theory which ascribes it to the lingering of germs about the infected place.

But by far the most interesting and important illustration of this filtering process is furnished by the human breath. If the ordinary air from the lungs be driven through a glass tube across the electric beam, the condensation of the aqueous vapour of the breath is shown by the formation of a luminous white cloud of delicate texture. It is necessary to abolish this cloud, and this may be done by drying the breath previous to its entering into the beam; or, still more simply, by warming the glass tube. When this is done the luminous track of the beam is for a time uninterrupted. The breath impresses upon the floating matter a transverse motion, the dust from the lungs making good the particles displaced. But after some time an obscure disc appears upon the beam, the darkness of which increases, until finally, towards the end of the expiration, the beam is, as it were, pierced by an intensely black hole, in which no particles whatever can be discerned. The air, in fact, has so lodged its dirt within the passage to the lungs as to render the last portions of the expired breath absolutely free from suspended matter. This experiment may be repeated any number of times with the same result. It renders the distribution of the dirt within the air-passages as manifest as if the chest were transparent.

If the lungs be emptied as perfectly as possible, and then filled with air inhaled through a handful of cotton wool, placed over the mouth and nostrils, on exdiring this air through the glass tube its freedom from floating matter is at once manifest. From the very beginning of the act of expiration the beam is pierced by a black aperture. The first puff from the lungs abolishes the illuminated dust and puts a patch of darkness in its place, and the darkness continues throughout the entire course of the expiration. When the tube is placed below the beam and moved to and fro the same smoke-like appearance as that obtained from a flame is observed. In short, the cotton wool, when used in sufficient quantity, completely intercepts the floating matter on its way to the lungs.

The application of these experiments is obvious. If a physician wishes to hold back from the lungs of his patient, or from his own, the germs by which contagious disease is said to be propagated, he will employ a cotton wool respirator. In the crowded dwellings of the London poor, where the isolation of the sick is difficult, if not impossible, the noxious air around the patient may, by this simple means, be restored to practical purity. Thus filtered, attendants may breathe the air unharmed. In all probability the protection of the lungs will be the protection of the entire system. For it is exceedingly probable that the germs which lodge in the air-passages, and which at their leisure can work their way across the mucous membrane, are those which sow in the body epidemic disease. If this be so, then disease can certainly be warded off by filters of cotton wool. And time will decide whether, in lung diseases also, the woollen respirator cannot abate irritation, if not arrest decay. M. Pasteur, in his most admirable work on this very important subject, has shown that the germs diminish as we ascend a mountain. By means of a cotton wool respirator, so far as the germs are concerned, the air of the Alps may be brought into the chamber of the invalid.

Filtration of Air for Respiration.—There are too many trades in England where life is shortened and rendered miserable by the introduction of matters into the lungs which might be kept out of them. Dr. Greenhorn has shown the stony grit deposited in the lungs of stone cutters. The black lungs of colliers is another case in point. In fact, a hundred obvious cases might be cited, and others that are not obvious might be added to them. A manufactory in one of our large towns, where iron vessels are enamelled by coating them with a mineral powder, and subjecting them to a heat sufficient to fuse the powder, was visited some time ago. The organization of the establishment was excellent, but one thing only was needed to make it faultless. In a large room a number of women were engaged covering the vessels. The air was laden with the fine dust, and their faces appeared as white and bloodless as the powder with which they worked. By the use of cotton wool respirators these women might be caused to breathe air more free from suspended matters than that of the open street. A Lancashire seedsman stated some time ago that during the seed season of each year his men suffered horribly from irritation and fever, so that many of them left his service. He was advised to try the efficacy of cotton wool, and he found that by simply folding a little cotton wool in muslin and tieing it in front of the mouth, that he could pass through the season in comfort, and without a single complaint from one of his men.

In a colour factory where much emerald green was packed for export, the men were subject to fits of vomiting, and showed other symptoms of arsenical poisoning; by the use of cotton wool respirators all these annoyances disappeared.

The substance has also been turned to other uses. An invalid placed at night a little of the wool before his mouth, slightly moistening it to make it adhere; he thereby prolonged his sleep, abated the irritation of his throat, and greatly mitigated a hacking cough from which he had long suffered. In fact, there is no doubt that this substance is capable of manifold useful applications. An objection was urged against the use of it, that it became wet and heated by the breath. Mr. Carrick, of Glasgow, invented a respirator which, though since superseded, met this objection. It was a metal contrivance, the lower part of which could be filled with medicated substances. In this case it was filled with the cotton wool. It was provided with two valves; and when fitted tightly round the lips the air entered the mouth through the cotton wool by one of the valves, which was lifted during the act of inhalation. During exhalation this valve was closed, and the breath escaped through the other valve into the open air. The wool is thus kept dry and cool, the air in passing through it being filtered of everything it holds in suspension.

In the discourse before referred to Dr. Tyndall continues:—" We have thus been led by our first unpractical experiments into a thicket of practical considerations. In taking the next step a personal peculiarity had some influence upon me. The only kind of fighting in which I take delight is the conflict of man with nature. I like to see a man conquer a peak or quench a conflagration. I remember clearly the interest I took twenty years ago in seeing the firemen of Berlin contending for mastery with a fire which had burst out somewhere near the Brandenburger Thor; and I have often experienced the same interest in the streets of London. Admiring as I do the energy and bravery of our firemen, and having heard that smoke was a greater enemy to them than flame itself, the desire arose of devising a fireman's respirator. Firemen have hitherto been dependent on the smoke-jacket, of which Captain Shaw says:—'It is very useful for extinguishing fires in vaults, stopping conflagrations in the holds of ships, and penetrating wells, quarries, mines, cesspools, &c.; any places, in short, where the air has become unfit for respiration: but its drawback is that it requires the use of an engine or air-pump, and consequently is of no service to one man alone. For this latter reason smoke-jackets, although very effective for enabling us to get into convenient places for extinguishing fires, have very rarely proved of any avail for *saving life*.'

" Now it is that very want that I thought ought to be supplied by a suitable respirator. Our fire-escapes are each in charge of a single man and I wished to be able to place it in the power of each of those men to penetrate through the densest smoke into the recesses of a house, and there to rescue those who would otherwise be suffocated or burnt. I thought that cotton wool, which so effectually arrested dust, might also be influential in arresting smoke. It was tried; but though found soothing in certain gentle kinds of smoke, it was no match for the pungent fumes of a resinous fire, which, according to Captain Shaw, evolves the most abominable smoke with which he is acquainted. I cast about for an improvement; and in conversing with my friend Dr. Debus, he suggested the use of glycerine to moisten the wool and render it more adhesive. In fact, this very substance had been employed by the most distinguished advocate of the doctrine of spontaneous generation, M. Pouchet, for the purpose of catching the atmospheric germs. He spread a film of glycerine on a plate of glass, urged air against the film, and examined the dust which stuck to it. The moistening of the cotton wool with this substance was a decided improvement; still the respirator only enabled us to remain in dense smoke for three or four minutes, after which the irritation became unendurable. Reflection suggested that in combustion so imperfect as the production of dense smoke implies, there must be numerous hydrocarbons produced, which, being in a state of nature, would be very imperfectly arrested by the cotton wool. These, in all probability, were the cause of the residual irritation; and if these could be removed a practically perfect respirator might possibly be obtained.

" All bodies possess the power of condensing in a greater or less degree gases and vapours upon their surfaces, and when the condensing body is very porous, or in a fine state of division, the force of condensation may produce very remarkable effects. Thus, a clean piece of platinum foil placed in a mixture of oxygen and hydrogen so squeezes the gases together as to cause them to combine; and if the experiment be made with care the heat of combination may raise the platinum to bright redness, so as to cause the remainder of the mixture to explode. The promptness of this action is greatly augmented by reducing the platinum to a state of fine division. A pellet of "spongy platinum," for instance, plunged into a mixture of oxygen and hydrogen causes the gases to explode instantly. In virtue of its extreme porosity, a similar power is possessed by charcoal. It is not strong enough to cause the oxygen and hydrogen to combine like the spongy platinum, but it so squeezes the more condensable vapours, and also acts with such condensing power upon the oxygen of the air, as to bring both within the combining distance, thus enabling the oxygen to attack and destroy the vapours in the pores of the charcoal. In this way effluvia of all kinds may be virtually burnt up; and this is the principle of the excellent charcoal respirators invented by Dr. STENHOUSE. Armed with one of these, you may go into the foulest-smelling places without having your nose offended.

"But while powerful to arrest vapours, the charcoal respirator is ineffectual as regards smoke. The particles get freely through the respirator. In a series of them tested, from half a minute to a minute was the limit of endurance. This might be exceeded by FARADAY'S method of emptying the lungs completely, and then filling them before going into a smoky atmosphere. In fact, each solid smoke particle is itself a bit of charcoal, and carries on it and in it its little load of irritating vapour. It is this, far more than the particles of carbon themselves, that produces the irritation. Hence two causes of offence are to be removed: the carbon particles which convey the irritant by adhesion and condensation, and the free vapour which accompanies the particles. The moistened cotton wool I knew would arrest the first, fragments of charcoal I hoped would stop the second. In the first fireman's respirator Mr. CARRICK'S arrangement of two valves, the one for inhalation, the other for exhalation, were preserved; but the portion of it which holds the filtering and absorbent substances was prolonged to a depth of four or five inches. On the partition of wire gauze at the bottom of the space which fronts the mouth is placed a layer of cotton wool moistened with glycerine, then a thin layer of dry wool, then a layer of charcoal fragments, a second thin layer of dry cotton wool, succeeded by a layer of fragments of caustic lime. In the densest smoke the layer of lime was not found necessary in a flaming building; indeed, the mixture of air with the smoke never permits the carbonic acid to become so dense as to be irrespirable; but in a place where the gas is present in undue quantity, the fragments of lime would materially mitigate its action.

"In a small cellar-like chamber, with stone flooring and stone walls, the first experiments were made. We placed there furnaces containing resinous pinewood, lighted the wood, and placing over it a lid which prevented too brisk a circulation of the air, generated dense volumes of smoke. With our eyes protected by suitable glasses, my assistant and I remained in this room for half an hour and more, when the smoke was so dense and pungent that a single inhalation through the undefended mouth would be perfectly unendurable: and we might have prolonged our stay for hours. Captain SHAW and three men of the fire brigade made trial of the respirator under the same conditions. On coming out they said that they had not suffered the slightest inconvenience; that they could have remained all day in the smoke."

The following are some of the practical adaptations of Professor TYNDALL'S dust and smoke filtering materials:—

The Smoke Cap of Captain Shaw.—This smoke cap consists mainly of two parts, called respectively the hood and the respirator. The hood is made of the best dressed calf skin blacked, cut in sections, and closed with air-tight joints, each part overlapping the next to the extent of half an inch, and the sections strongly sewn together with two separate rows of saddlers' stitching. The skull part is fitted to the shape of a man's head, and is about 24 inches in circumference at the widest part; underneath this there is a band about 2 inches deep, forming a kind of yoke or apron piece about 6 inches deep, shaped to fit on a man's chest and shoulders under a tunic.

To facilitate the putting on and taking off of the hood, there is an opening down the whole of the back part, from the crown to the neck, and on each side of this opening is a row of four eyelet holes with brass bushes. Through these holes there is rove as a lacing leather thongs, the ends of which go round to the front, and after passing through a small metal lining are knotted at the ends below two wooden knobs, to prevent their being pulled back through the ring. When the hood has been put on the thongs are pulled in front, and rendering through the eyelet holes, draw the whole of the skull part close to the head. The opening at the back is fitted with a piece of what is commonly known as waterproof sheeting, a thin air-tight material which occupies very little space, and although wide enough to allow the head to enter freely is easily folded away by the drawing of the thongs. The lower flap or apron part is tucked in under the collar of a tunic, so as to form an air-tight joint sufficient for the purpose.

To the front of the hood inside is attached, by means of brass rivets, a tinned sheet of metal shaped to fit the front of a man's face, from the bridge of the nose to the chin. Into this, opposite to the mouth, is fixed a hard wooden mouthpiece.

At a distance of about 4 inches above the mouthpiece there are fixed a pair of curved eye-glasses of the best clear glass, set with cement in brass fittings, which are attached by screws to curved metal frames riveted on the inside of the hood.

The respirator consists of two parts, the valve chamber and the filter tube.

The valve chamber is a brass tube 2 inches long and 2 inches in diameter, with an upper and lower valve plate. Between the two plates is soldered and riveted a brass connecting piece, by means of which the respirator is attached to the hood.

Each of the valve plates is fitted with three ebonite ball valves, half an inch in diameter, turned perfectly round, and without the slightest projection or rim in any part. The openings in the plates are $\frac{5}{16}$th inch in diameter, and are cut, that the seatings embrace at least one-third of the valves. The seatings, which are separate pieces, are screwed into the plates, and are most carefully bevelled out, so that the valves shall make an exact fit.

Above the valves there is screwed on a cap-plate, which protects the valves from injury. It is pierced round the edge with twenty-eight holes for the escape of the discharged air.

The filter tube, which is screwed to the valve-chamber, is also of brass. It is of the same diameter as the valve-chamber, and is 4 inches long. Across its upper end is soldered a piece of fine wire gauze, which prevents the filtering materials passing. Over its lower end there is screwed on a brass ring or cup, with a similar piece of wire gauze; this, while allowing the air to pass, prevents the filtering materials from falling out.

The charge for the filter consists of the following:—Half an inch deep of dry cotton wool, an inch deep of the same wool saturated with glycerine, half an inch deep of dry wool, an inch deep of fragments of charcoal, and an inch deep of dry wool. In filling, the respirator is turned upside down, and the materials are packed so as to fill every part of the chamber, and pressed down as tightly as experience shows to be compatible with facility of breathing when in use. After this the grating cap is screwed on, and the filter is then ready for use. A layer of caustic lime is introduced when using the apparatus in carbonic-acid charged atmospheres.

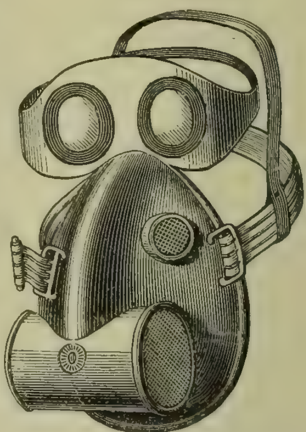
The total weight of this respirator when charged and ready for use is 2½ lbs.

In putting on the smoke cap it is held with the face part downward, the hood is then slipped over the head, and as soon as the top rests on the top of the head, the wooden mouthpiece is adjusted in the mouth; this brings the eye-glasses and other parts into their proper positions. The lower flaps are then tucked under the tunic of the wearer, and the thongs hanging in front are tightly pulled until the lacing at the back draws the skull part closely round the head. After this the tunic is buttoned up to the neck, the helmet is put on, and then all is in readiness for working in a densely smoke-laden atmosphere.

Face Piece and Respirator.—This apparatus, which is represented in the annexed cut, is a thin soft metal cover, having fixed around its edge a soft india-rubber tube filled with water. When placed upon the face of the wearer, it fits air-tight around the nose and mouth. In the upper part of one side is fixed a cylinder of ebonite, of about an inch in diameter, having a $\frac{3}{8}$th of an inch hole bored through it. Attached to, and covering the outer end of this cylinder (which is perfectly flat and smooth), is a flap of vulcanized india-rubber. This flap lies in close contact to the smooth end of the cylinder, and forms an excellent respiratory valve. This valve is protected from injury by a wire gauze cover.

To the lower part of the face piece is attached the filter tube, a tin cylinder 3½ inches long and 2 inches in diameter, one end of which opens into the interior of the face piece. The other end is fitted with a movable wire gauze cap, which prevents the filtering materials falling out. Associated with the face piece, but not attached to it, is a broad vulcanized india-rubber band, into which is inserted two ebonite rings. Into the ebonite rings are fitted air-tight strong curved glasses, similar to watch glasses. The arrangement of the materials in the filter chamber are the same as used in the filter chamber of the smoke cap.

Fig. 1.



In adjusting the apparatus, the vulcanized india-rubber band is stretched over the upper part of the face by means of an elastic band which passes round the head. The curved glasses are adjusted to suit the position of the eyes, and the broad band of india-rubber being thus pressed into the indentations of the face, completely protects the eyes from smoke.

The metal face piece is now placed over the nose and mouth and secured in position by means of an elastic strap, which passes from one side of the face piece around the head, and is made fast to a buckle attached to the other side. A band attached to the elastic strap fits over the top of the head and prevents the face piece falling below its proper position.

During inspiration the air passes through the filtering materials in the tin cylinder into the face piece, to the mouth and nose. During expiration, the air from the lungs is ejected through the expiratory valve into the open air.

The advantage of this form of smoke respirator is, that the wearer can respire through the nose as well as through the mouth. Also, the mouth being perfectly free there is no excessive secretion of saliva, which in the smoke cap (owing to the wearer respiring only through a wooden tube held in the mouth) is considerable.

Dust Filter.—The face piece above described is fitted with a tin cylinder of the same form, but of smaller dimensions than that used for the filtration of smoke. It is entirely filled with dry cotton wool. When in use, it is attached to the face of the wearer in the same manner as described above. The glass protectors for the eyes are, of course, not used.

Cottrell's Face Piece.—The most recent form of the smoke respirator is constructed (with exception of the filter chamber and the glass eye-protectors) entirely of vulcanized india-rubber.

A sheet of vulcanized india-rubber about 10 inches long and 7 inches wide has (at about 2 inches from one edge, and midway from each end) an aperture cut, of such shape and dimensions as to allow the lips to protrude. Above this another aperture is cut, which allows the nose to pass easily through it. On each side of the nose aperture, and a little above it, a circular hole is cut corresponding to the position of the eyes.

A bent tin cylinder 4½ inches long and 2 inches diameter (having a curvature nearly corresponding to the curvature of the face) is firmly and securely fixed opposite to, and forming a closed chamber around the mouth aperture, by means of strips of sheet india-rubber.

The nose aperture is covered with sheet rubber, forming a chamber sufficiently large for the protruding nose. The lower ends of the nose cover are attached to the rubber sheet supports of the tin cylinder, in such a manner as to connect the nose and mouth apertures by a small chamber.

Into each hole corresponding to the eyes a circular curved glass about 1¾ inch diameter (similar to a watch glass), held in a suitable fitting, is inserted.

One end of the tin cylinder is closed by an india-rubber valve, opening outwards. This valve is protected by a movable wire gauze covering.

The side of the tin cylinder, a little below the valve, is pierced by a hole, covered with wire gauze, which opens into the mouth chamber. The other end of the tin cylinder is fitted with a movable wire gauze covering, which prevents the filtering materials from falling out.

The filtering materials are the same as previously employed.

The apparatus when in use is secured to the head of the wearer by two narrow elastic straps, one of which passes from the upper part of the apparatus round the head; the other passes from the lower part of the apparatus round the neck. With a little pressure of the straps, the flexible sheet india-rubber of the face piece is drawn air-tight into the indentations of the face, and around the mouth and nose.

During inspiration the valve is closed by atmospheric pressure, and the air passes through the filtering materials in the tin cylinder through the hole (below the valve) opening into the mouth chamber, to the mouth and nose. During expiration the air is ejected from the lungs through the outward opening valve into the open air.

The total weight of the apparatus when charged with the filtering materials is about 9 ozs.

Its advantages over previous forms are its lightness, simplicity of construction, and cheapness; the ease and rapidity of adjustment; no undue heating of the head, the face only being covered; no chance of derangement by the bursting of water tubes, &c., as none are used. As in the face-piece, the wearer can respire through the nose as well as through the mouth. In this case also, the mouth being free from any air-tube, there is no excessive secretion of saliva.

Cottrell's Dust Filter.—This is an apparatus constructed of very light vulcanized rubber. It is similar in shape and constructon to the smoke respirator, but the part above the nose, containing the curved glass protectors, is removed. Wire springs are introduced on each side of the nose, so as to press the edges of the rubber sheet into the indentations of the face. The cotton wool chamber is much smaller than the filter chamber of the smoke respirator, and is constructed of light wire gauze, covered with thin sheet rubber. In use, it is held in position by a single elastic band passing round the head. The whole thing, when charged complete, is exceedingly light, and can be worn for a long period without inconvenience.

Natural Disinfectants.—Pure air is a disinfectant, and shows its beneficial action by the effects of good ventilation, which carries away, starves, and destroys the organic germs which cause infection. Stagnant air is incapable of disinfecting the usual vitiation of towns, or even of the country, with sufficient rapidity, much less can it purify a room subjected to any source of foulness; but when a current comes and mixes the vapours from the earth with the enormous expanse of air above, or carries them away to the ocean, there is then given to them space for purification, the particles are disintegrated thoroughly and oxidized, and living germs die for want of nutriment, so that before the same air can again come into contact with human beings, it is rendered perfectly innocuous.

Under this head comes ventilation, details of which as a purely mechanical means of disinfection would be out of place here. Nevertheless it is a study of great importance, and in the construction of large rooms, hospital wards, and even in ordinary dwellings, it should have special attention, as health is dependent on its being thorough.

Water is the next great natural disinfectant. It is true that moist bodies decay more rapidly than others, and that a certain amount of humidity is essential to eremacausis; water is, therefore, both a great corrupter and a great purifier, according to the circumstances of the case. Water in quantity is a disinfecting agent by the simple act of washing; this is its mechanical, and probably its most important effect. In this way each shower of rain becomes a natural disinfectant to the atmosphere, bringing down with it the floating organic substances and diffused gases. Every river is a great remover of substances capable of decomposition, but, however pure it may be, if water be allowed to remain stagnant for a short time, it will be found that there will soon be matter enough in it to cause putrefaction. The ocean also disperses the decaying material abroad, removes it from the land, mixes it with purer water, dashes it about in the air, and thus produces purification. Water is the only fluid that will communicate to the skin the feeling of freshness, an accompaniment of cleanliness, and so exceedingly liked by every person that it must be pronounced a most natural and wholesome condition; indeed, so much is freshness generally esteemed, that it stands in the language as a very type of vigour and beauty. In all cases where water will remove the evil, it ought to be used as the most efficient and agreeable.

Soil is another great disinfectant, and, in conjunction with air and water, is the most efficient of all. The water carries into the soil the impurities it meets with; the air penetrates the water, and is powerfully retained by the soil, and by this means the organic and putrid substances are brought into contact with the oxygen, and oxidation is made forcibly to take place. Hence a field manured with the most fetid compounds gives off no smell after the lapse of a few days, or even hours, and the water drained from it possesses no special odour, provided the drains be sufficiently deep. Were it not for this agency men and animals would soon render the country uninhabitable. From this cause, too, the soil of a city is freed from impurities, and instead of albuminous bodies containing nitrogen being found in it, the nitrogen is oxidized, and nitrates are formed, except in instances where the abundance of animal matter is more than can be acted on by the soil.

The greatest remedial measures that can be adopted for the general disinfection of a country are, therefore, air, water, and land drainage, all to some extent under the power of man; the latter almost entirely so.

There are two agencies, partly natural and partly artificial, which check decomposition, and in suitable conditions entirely arrest it; these are heat and cold: it is necessary to treat them as distinct, because they present themselves as such. The former prevents decay by drying, as well as by changing the chemical state of substances.

It has been assumed that a temperature of 200° Fahr. was sufficient to destroy the living organisms in fœtid matter; but the experiments of the late Dr. Crace Calvert, F.R.S., tend rather to prove that heat alone, even far above that temperature, does not entirely render it innocuous, but merely checks the development of protoplasmic life; and his experiments are confirmed by Dr. Beale, who states that "living forms might live though exposed under certain conditions to a temperature of 350° Fahr."

It is still a matter of keen controversy as to the temperature required to destroy the vitality of living germs and minute infusorial matter so as to render infectious matter inert.

Heat should be employed for disinfecting purposes when available, and if used in conjunction with certain artificial disinfectants, and according to the plan adopted in several large towns, in the disinfecting stoves and ovens for infected clothing, all chance of infection will be removed.

Cold, of all antiseptics and disinfectants, is the most powerful, since growth and decomposition, the result of germ growth, cannot go on when the temperature sinks below about 35° Fahr.; it can, however, seldom be had recourse to, because not completely under control; and when it can be commanded, it cannot be applied to living beings, and it may be added, that when it is removed the former condition again sets in. The ice-buried animals in the North are a well-known example. Under the influence of intense cold chemical action ceases; particles of flesh remain firmly united, as if they were in reality what they resemble in hardness—a piece of rock.

Artificial Disinfectants.—So many different substances have at various times been proposed and used with more or less effect as disinfectants, that it would be impossible in the limits of our space to give a description of each, and therefore we shall confine ourselves to the following as being the more important ones:—

Carbolic acid.
Cresyl alcohol.
Salicylic acid.
Chlorine.
Chlorides of zinc and lime.
Sulphurous acid and sulphites.
Metallic sulphates.
Permanganate of potash.

Carbolic acid, *Phenol*, *Phenyl hydrate*, *Phenyl alcohol*, *Phenic acid*, *Coal-tar creosote* ($C_6H_6O = C_6H_5OH$).—This body is contained in coal tar. It is prepared commercially by distilling the tar until anthracene makes its appearance. The resulting volatile oils are redistilled, and that part which is volatilized between 150° and 200° C. collected, mixed with potash liquor and powdered potassium hydrate, by which it is precipitated as a white crystalline powder. This is dissolved in hot water, when an oily matter rises to the surface, which is skimmed off. The alkaline liquor is then neutralized with hydrochloric acid, and the impure phenyl hydrate which rises to the surface is washed with water and rectified over chloride of calcium. Addition of a few crystals of pure phenol to that portion of the distillate which comes over between 186° and 188° causes a large part of the phenol to solidify at once, and thus materially shortens the operation. It can then be purified by sublimation.

Commercial carbolic acid is generally very impure. The liquid acid is frequently adulterated with tar oils, which decrease its value considerably, and seriously deteriorate its disinfecting powers, rendering it at the same time insoluble or nearly so in water.

The following is a ready method of testing its purity.

Put one volume of the liquid to be tested into a graduated glass measure, and add two volumes of a solution of caustic soda 14° Twaddell, at 60° Fahr., and shake them well together for about a minute. If the carbolic acid is genuine it will be dissolved in the caustic soda solution, and the solution will appear bright and clear; but if any tar oils are present they will either float on the surface or sink to the bottom of the tube, according as they are light or heavy oils of tar. Carbolic acid containing tar oil should be rejected.

As a convenient form for disinfecting purposes, disinfecting powder consisting of lime and carbolic acid is prepared, and according to the percentage of carbolic acid it contains does its efficacy depend.

The following is an easy method of determining the percentage contained by the powder, as the various carbolic disinfecting powders offered for sale contain from 1 to 15 per cent. of carbolic acid.

Weigh 1000 grs. of the powder, and place it in a small tubulated retort.

Heat the retort gradually until the liquid distilled ceases to drop (a brisk heat is required towards the end of the operation).

Collect the distillate, which will condense in the tube of the retort, in a graduated cylinder grain measure, and allow it to settle for an hour, when the amount of oily liquid and water may be read off.

The oily liquid should represent the amount of carbolic acid, and to determine if it consists of carbolic acid, to one volume of it add two volumes of a solution of pure caustic soda, 14° Twaddell's hydrometer, at 60° Fahr., which will entirely dissolve the carbolic acid.

If any remains undissolved it will probably consist of either heavy or light oil of tar, the most frequent adulterants of carbolic acid, and in some cases entirely substituting it.

The above process will, if carefully worked, give within one per cent. of the amount of carbolic acid really contained by the powder.

Cresol, *Cresylic phenol*, *Cresyl alcohol* ($C_7H_8O = C_6H_4OH.CH_3$) is likewise contained in coal tar; it is prepared by fractional distillation of coal-tar creosote, as a liquid boiling at 203° C. It is a homologue of phenyl alcohol, into which it is decomposed by repeated distillation by the oxidizing action of the air in an atmosphere of hydrogen: distillation for any number of times leaves it unaltered.

Salicylic acid ($C_7H_6O_3 = C_6H_4\left\{\begin{matrix}OH\\COOH\end{matrix}\right)$, *meta-oxybenzoic acid.*—Salicin ($C_{13}H_{18}O_7$) is a glucoside or neutral vegetable principle, which was discovered by Leroux in 1830 in the bark of the willow, *salix*, whence its name. It was afterwards found in various species of poplar, and in other trees and plants. Piria prepared salicylic acid from salicin by melting it with potassium hydrate. Löwig and Weidmann found that it was contained in the flowers of *Spiræa ulmaria* (meadow sweet); and later Procter showed that oil of winter green, *Gaultheria procumbens*, was really a salicylous ether, and from this source salicylic acid was obtained by Cahours.

Within the last few years German chemists have investigated its properties, and have discovered its powerful action as an antiferment and antiseptic. These reactions producing a demand for it, Kolbe and Lautemann sought for an organic compound which, from its elementary composition, might be split up into the desired acid. This substance they found in phenol (carbolic acid). On dissolving sodium in hot phenol in the presence of a stream of carbonic acid, there is always formed, besides sodic salicylate, more or less sodic carbonate and phenylate. They also observed that the more of the former salt there was, the less was found of the two latter. Moreover, a product rich in sodic phenylate, and relatively poor in sodic salicylate, yields the latter salt freely when further heated in a stream of carbonic acid.

Upon these reactions Kolbe founded a process which is now carried out on a large scale; and which he describes as follows:—

Saturate exactly commercial crude soda lye of known strength with crystallized carbolic acid previously fused, and evaporate in a shallow iron vessel, taking care that the sticky dough-like mass does not adhere to the bottom of the vessel as it becomes dry; the mass is constantly crushed with pestles until the sodic phenylate remains as a perfectly dust-dry powder. It is always reddish yellow in colour, perhaps on account of partial decomposition by the oxygen of the air during the evaporation, is very hygroscopic, and must while yet hot be excluded the air.

If the sodic phenylate is moist, or contains either free alkali or carbolic acid, the result is not good, a dark-coloured substance being formed, which, when it undergoes the final process of treatment with carbonic acid gas, gives far less salicylic acid than is in accordance with the amount of calculated phenylate present.

The dry sodic phenylate is then either filled into the retorts at once, or it may be kept for further treatment by filling it when hot in vessels which can be hermetically sealed.

After filling the retorts the contents are slowly heated to 100° C., and when this temperature is reached, a slow current of perfectly dry carbonic acid gas is allowed to enter the retort. The temperature is then slowly increased to 180° C., and may, towards the end of the operation, reach from 220° C. to 250° C.

About an hour after beginning the operation carbolic acid will begin to distil, and the process may be considered finished if, at the latter mentioned temperature (220° to 250° C.), no more carbolic acid distils. It will then be found that the distilled carbolic acid amounts to just half of the original quantity employed.

The residue in the retort is basic sodic salicylate, which is dissolved, and which, on being acidified with an acid, yields a brownish coloured crystalline precipitate of salicylic acid.

The further process of decolorizing the salicylic acid was not described by Kolbe, but Rautert states that this colouring may be removed by heating it to 170° C. in a retort, and then injecting a current of superheated steam of the same temperature. Colourless salicylic acid distils at once, and after a short time nothing but a trace of a black resinous mass remains in the retort. The apparatus must be arranged in such a manner that the neck of the retort can by mechanical means, as for instance a movable wire, be kept free from crystals.

An exceedingly interesting reaction takes place, according to Endemann, if potash is substituted for soda in the above process; the resulting acid is under these circumstances not salicylic, but pure oxybenzoic acid, a substance which is isomeric with salicylic acid, and according to Kolbe's experiments without any disinfecting properties whatever. If the process, however, is carried out with potash, but at a temperature not exceeding 145° C., Hartmann states that the resulting acid is in this case also salicylic acid.

Baryta, strontia, lime, and magnesia, furnish at 220° C. salicylic acid, and therefore act like soda.—OST.

If in KOLBE'S process for the manufacture of salicylic acid, cresol (cresyl alcohol, C_7H_8O) be substituted for phenol, cresotic acid is formed, which shares with salicylic acid the disinfecting properties. A non-crystalline carbolic acid containing cresol may, therefore, be used for the manufacture of salicylic acid, as the disinfecting properties of the product are not diminished by its containing some cresotic acid.

For medical internal use, however, the two products ought to be kept strictly apart until the physiological effects of each have been well defined.

Salicylic acid is odourless. It has a sweetish and astringent after taste, though itself tasteless. It is sold in minute broken acicular crystals, which give it the appearance of a granular powder, soft and smooth under the pestle or knife, but somewhat rough when rubbed between the fingers. It is insoluble in cold, but very soluble in hot water; and the water of a hot solution retains when cold, in proportion to its temperature, from about 1 part in 250 to 1 part in 500 in solution. The presence of various neutral salts in small proportion in the water render it more soluble.

Up to this time sodic phosphate has been used in Germany to render it more soluble in water for medicinal purposes, and it is said that 3 parts of sodic phosphate will render 1 part of the acid easily soluble in 50 parts of water. It is much more soluble in alcohol and ether than in water. It melts at about 125° C. (257° Fahr.) and sublimes at 200° C. (392° Fahr.).

Salicylic acid is used for medical and surgical purposes either dry or in solution. When used dry it is mixed with some diluent, generally starch, and sprinkled on the wound or dressings in the form of a very fine powder.

When used in solution either for spraying surfaces or for washes or gargles, it is used in tepid solution of about 1 part in 300 parts of water.

Salicylic acid is effective as an antiseptic in very small quantities, and is at the same time entirely devoid of irritant action upon living tissues. It is not caustic in small quantity and never produces inflammation. It averts and prevents processes of decomposition both vital and chemical—vital, or those in which living organisms have a part, such as that produced by yeast, and many of those which occur in putrefaction; and chemical, or those which occur independently of vitality, as the production of the volatile oils in mustard and bitter almonds, the effect of diastase, &c. In quantities thoroughly effective for disinfecting purposes it is entirely odourless, tasteless, and is not poisonous.

DISINFECTION. — Phenol and cresol, which are closely allied, hold the foremost place among disinfectants, both on account of their cheapness and efficiency, and because they can be employed either in solution or vapour.

These two substances are derivatives of coal tar. The carbolic acid usually employed for disinfecting purposes is either in the form of detached crystals, containing a large percentage of carbolic acid with a small percentage of cresyl alcohol, soluble in about 60 parts of water; or in a liquid form, containing a smaller percentage of carbolic acid with a larger percentage of cresyl alcohol, and soluble in about 80 parts of water.

A very dilute solution of either of these acids is sufficient to destroy infusorial life. From experiments made at the Morgue in Paris, M. DEVERGIE remarks, "that during the heat in summer, when putrefying corpses in the Morgue continually emit a quantity of noxious gases that cannot be removed by ventilation. or destroyed by chlorine or bleaching powder, we decided to prevent their production by trying to destroy the vitality of the germs of putrefaction, and thus prevent decomposition itself. We effected this by dissolving 1 litre of carbolic acid in a reservoir holding 1900 litres of water, and irrigating the bodies with the solution thus made; putrefaction was completely stopped, and disinfection was even obtained after reducing the quantity of acid by one half. M. DEVERGIE points out that water containing $\frac{1}{4000}$th part of carbolic acid proved sufficient during the intense heat of a Paris summer to disinfect the dead-house without aid of any shaft, when six or seven bodies were lying there."

The late Dr. F. CRACE CALVERT, F.R.S., gives the following table of experiments made by him with several antiseptics. He placed solutions of albumen and flour paste in uncorked bottles, and added to them the antiseptics with the following results:—

		Time in which it acquired an offensive odour. Temperature 70° to 80° Fahr.	
Antiseptic employed.	Percentage of Antiseptic.	Albumen.	Flour paste.
Chloride of aluminium (made lately),..........	2 ..	9 days. ..	10 days.
Chloride of zinc,..........	2 ..	15 " ..	Remained sound.
Chloride of lime,..........	5 ..	16 " ..	14 days.
Permanganate of potash,..	5 ..	4 " ..	6 "
Tar oil,..,..............	2 ..	11 " .	25 "
Carbolic acid,............	2 ..	Remained sound.	Remained sound.
Cresyl alcohol,..........	2 ..	Remained sound.	Remained sound.
None,...................	– ..	5 days.	7 days.

He further adds, "The above table clearly shows that the only true antiseptics are carbolic acid and cresyl alcohol, and these results coincide with those obtained by Mr. WILLIAM CROOKES, F.R.S., Dr. ANGUS SMITH, F.R.S., and Dr. SANSOM. For these two acids continued their action till the albumen solution and paste dried up.

"It follows that if deodorizers are merely required for removing the noxious odour from any mass of matter in a state of decay or decomposition, they may be used with advantage; such are chlorides of manganese, lime, sulphate of iron, permanganate of potash, and aluminium. But if it is desirable to prevent the decomposition of organic matter (and in my opinion this is the point to be aimed at, for prevention is better than cure), then carbolic and cresylic acids are the only two substances which attained this object."

As the products given off from decaying organic matter are well known to facilitate the decomposition of similar classes of substances to themselves, if placed in close proximity (no doubt by the atmosphere conveying the germs), Dr. CRACE CALVERT made the following experiments with the view of ascertaining which of the undermentioned substances would possess the most active power in destroying such germs, and thus preserving the animal substance from decay. At the bottom of wide-mouthed pint bottles he placed a known quantity of each of the antiseptics, and suspended over them by a thread a piece of sound meat, and by daily examination it was easily ascertained when the meat became tainted or putrid. The following table gives the results obtained:—

Antiseptic.	Became tainted.	Putrid.
Permanganate of potash, ...	2 days.....	4 days.
Chloride of aluminium, ...	2 days.....	10 days.
Chloride of lime, ...	14 days.....	21 days.
Tar oil, ...	16 days.....	25 days.
Chloride of zinc,...........	19 days	—
Carbolic acid, ...	Did not become tainted, but dried up, and became quite hard.	
Cresyl alcohol,............	Do.,	do.

The comparative value of antiseptics is also shown by the following carefully executed series of experiments made by S. BUCHOLTZ, to determine the different amounts of each which would check the putrefaction of a liquid of known composition. The PASTEUR'S liquid he used was a solution of 10 grammes of common sugar, 1 gramme of tartrate of ammonia, and half a gramme of phosphate of potassium in 100 c.c. of distilled water. The amount of any antiseptic needed to prevent the putrefaction of this liquid was easily determined by filling a number of tubes with it, adding different amounts of the antiseptic to them, and then watching the results of their impregnation with a few drops of a decomposing infusion of tobacco.

The results of these experiments are given in the following tables:—

Smallest amount which prevented the development of bacteria:—

	1 part in
Corrosive sublimate, ...	20,000
Thymol, ...	2,000
Sodium benzoate,.....................	2,000
Creosote, ...	2,000
Benzoic acid, ...	1,000
Methyl salicylic acid,................	1,000
Salicylic acid,......................	666
Eucalyptol....	666
Sodium salicylate,...................	250
Carbolic acid, ...	200
Quinine, ...	200
Sulphuric acid, ...	151
Boracic acid, ...	133
Cupric sulphate,.....................	133
Hydrochloric acid, ...	75
Zinc sulphate,.......................	50
Alcohol, ...	50

Smallest amount which would stop putrefaction and render the bacteria incapable of further development when removed to fresh PASTEUR'S solution:—

	1 part in
Chlorine,..........................	25,000
Iodine, ...	5,000
Bromine,...........................	3,333
Sulphurous acid, ...	666
Salicylic acid, ...	312
Benzoic acid, ...	250
Methyl salicylic acid,....	200
Sulphuric acid, ...	161
Creosote,..........................	100
Carbolic acid, ...	25
Alcohol, ...	4.5

The late Dr. LETHEBY states that in his experiments in the city of London, he found that a very small quantity of carbolic acid in the sewers prevented decomposition, and that a solution of one per cent. of it upon meat arrested putrefaction.

Dr. BAKEWELL, formerly a medical officer of health for Trinidad, makes the following statements with regard to carbolic acid.

"I can bear testimony to the efficacy of carbolic acid in removing all offensive smell, and its usefulness as a topical stimulant for weak or sloughing sores. I employed it largely as a disinfectant, and particularly for cases of yellow fever, during the late epidemic in Trinidad. I had it used in all the houses where cases occurred; and when I had to inspect drains, cesspools, or places where there had been contagious sickness, I always carried a little about with me to smell whilst inspecting; without this I could not have performed my duties, so fearful are some of the stenches in the tropics. My assistants were glad to adopt the same plan.

"The advantages peculiar to carbolic acid over other disinfectants are: 1st, volatility; 2nd, cheapness; 3rd, its smell, which enables one always to know when a sufficiency has been used; 4th, the fact that it can be employed as a solid, a liquid, and a vapour; 5th, the small quantity required, and hence its portability.

"I recommend that a bottle of the acid or tin of the powder be kept in every privy or water closet, so that a little may be thrown down by each person using it; by this plan all offensive smell will be prevented. I may just add, that I find it extremely useful in contagious dysentery and typhoid fever, to disinfect the evacuations."

In a report made by Dr. TRENCH, the medical officer of health for Liverpool, in December, 1869, he remarks, "There need be no controversy as to the comparative value of the different disinfectants, such as sulphate of iron, sulphate of zinc, chloride of lime, permanganate of potash, quicklime, charcoal powder, carbolic acid. They all have their special modes of action, and each may be occasionally the very best to be employed.

"In choosing carbolic acid as a disinfectant, I am influenced by its price and its efficiency. 1. It is a positive disinfectant, and quickly destroys or restrains every contagious and infectious virus. 2. It is an antiseptic, and arrests and prevents fermentation and decay. 3. It is used with facility, and is sufficiently volatile to permit its vapour to reach atoms or germs of disease floating in the air. 4. It is cheaper than chloride of lime, and for out-door disinfection, as well as the disinfection of privies and drains, it is more permanently efficacious."

Messrs F. C. CALVERT & Co., the manufacturers of this product, give the following directions as to its use:—

"Directions for the use of Carbolic Acid Crystals.—The crystallized carbolic acid is soluble in water, and *one pound to every five gallons of water* is sufficient for deodorizing and disinfecting purposes.

"The bottles, when opened, should be placed in the water for about one hour (according to the temperature). 4, 8, or 12 of the bottles, which each contain a pound, being used for a tank of either 20, 40, or 60 gallons. The bottles should be cleared of all adhering crystals, and the solution well stirred previous to use.

"A solution of this strength is applicable for deodorizing of sinks, water closets, or wherever bad odours exist, and being neither alkaline, acid, nor corrosive, no injury need be apprehended to wood, iron, metal, or clothes. In a concentrated form the acid acts as a caustic, but its action on the skin may readily be arrested by rubbing with sweet oil.

"*For hospital wards, night asylums, &c.*—To keep them in a healthy state, and to prevent any spread of contagious diseases, dissolve 1 lb. of crystallized carbolic acid in 30 gallons of water, and sprinkle the floors with the solution, which may also be employed for deodorizing the chamber utensils.

"The solution may be used in *fœtid ulcers, cancers, gangrenous and all offensive sores;* it removes all disagreeable smell and putrescency, and renders the discharge innocuous to the contiguous living and unaffected tissues. In its diluted state, therefore, it is a great boon to patients labouring under that class of disease.

"*When small-pox, typhoid fevers, &c.*, occur, the spread of contagion may be prevented by proper use of this disinfectant. In such cases the acid should be used in the crystalline form, viz., 1 lb. of the crystals to 5 or more lbs. of wet sand, placed in shallow vessels in various parts of the sick room.

"In case of any epidemic breaking out in a house, the same mixture should be used as a sanitary precaution *throughout the same.*

"*Infected clothing and bed linen* can be thoroughly purified and rendered fit for use, if well washed in the aqueous solution."

The liquid acid may be used in a similar manner. The disinfecting powder supplied by them contains fifteen per cent. of carbolic acid and cresyl alcohol, and is employed as follows:—

"*For sick rooms.*—Placed in dishes about the room, this powder gives off carbolic acid freely; it must be renewed once in twenty-four hours. Infected clothing and bed linen can be purified and made fit for use, if well washed in water into which $\frac{1}{4}$ lb. powder has been mixed with each bucket-full.

"*As a disinfectant.*—The powder may be used by mixing one lb. in a bucket of water; or by sprinkling it lightly over the surface to be disinfected.

"*For dead bodies.*—Spread over the bottom of the coffin 2 lbs. of the powder before putting the body in; then dip a sheet in a solution of the powder (1 lb. to a gallon of water) and cover the body with it; this will prevent any effluvia or disease being disseminated therefrom."

Carbolic acid is also used in the form of vapour for purifying the atmosphere of hospital wards, and other places where contagious diseases exist. Half an ounce of acid is sufficient for an ordinary sized sick room.

A very convenient form of vaporizer is one designed by R. Le Neve Foster, F.C.S., Figs. 2 and 3.

"The iron heater A is to be placed in a fire until it has the required temperature, when it is to be removed by the hook, B, and placed in the box, C; the lid D must then be closed.

Fig. 2.

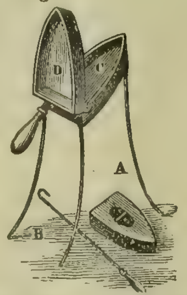
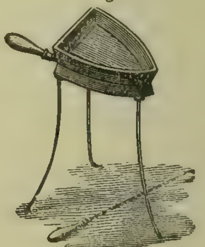


Fig. 3.



"The carbolic acid is then poured into the enamelled dish above the lid, and in a few minutes the carbolic vapours will be given off and diffused throughout the atmosphere of the place to be fumigated."

The following is the method of disinfection carried out in Bristol by Dr. Davies, the medical officer of health, as described by him.

"The city is divided into four districts; each district has an inspector in it—there is also a superintendent inspector; each district inspector in the summer time has two workmen at his command, and one in winter, to white-lime dirty walls, courts, and alleys, to let off foul ejects in privies, &c. They carry with them a bucket of Calvert's powder, which they sprinkle over the pans, &c., of the closets, over every street grating, and every eject they pass. When we suspect any division of the sewers to have the germs of disease in it, we throw in a considerable quantity of sulphate of iron and of liquid carbolic acid.

"I meet the district inspectors daily at 11 a.m., and if they report any disease of a zymotic character among the poor, I visit the affected persons, and order the floor to be thickly sprinkled with carbolic disinfecting powder. I supply the friends with it gratuitously, and order them to keep the chamber utensils always charged with it. If the patient dies, we supply some to be sprinkled over the corpse.

"Being a strong believer in the germinal origin of all zymotic disease, I have followed this plan with unwavering firmness, and I can only say that our success here has been very extraordinary, as testified by our death rate. Houses affected with zymotic disease we treat, after the removal of the patient, under the 22nd section of the Sanitary Act, 1866.

"In one or two minor matters I differ with other reporters. The powder, if fresh, is not innocuous to the hands; our workmen used to sprinkle it with their hands, but were obliged to desist on account of its irritating the skin—they now use small hand ladles.

"If sprinkled over French-polished furniture it spots them; it does not hurt metals, boards, or clothing; it never produces irritation of the lungs, though some persons dislike it, and complain of nausea when exposed to it."

Carbolic acid soaps are another form of using this valuable antiseptic.

Salicylic acid is allied to carbolic acid, and possesses exceedingly valuable antiseptic properties. It is made in the form of a powder, devoid of smell, and is soluble in about 300 parts of water.

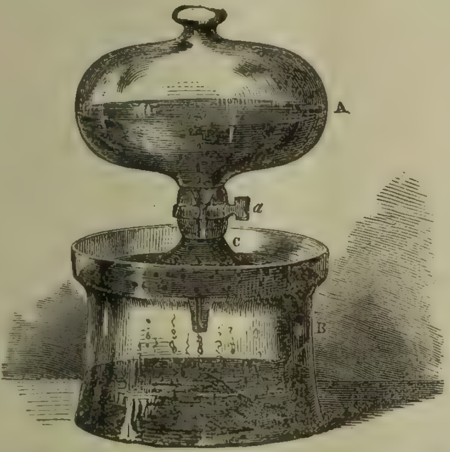
Salicylic acid has not yet been produced on a sufficiently commercial scale to come into use as a general disinfectant, though many experimental tests have shown that for some purposes it surpasses carbolic acid.

Chlorine, Chlorides of Zinc, Lime, and Aluminum.—Of these, chlorine doubtless holds the foremost place. Chlorine is prepared by heating a mixture of black oxide of manganese with hydrochloric acid.

Fig 4 is a representation of an ingenious and simple contrivance for liberating chlorine.

Having introduced the binoxide of manganese into the glass basin B, put on the perforated wooden cover, C, fix the globular vessel, A, in the orifice, and pour a quantity of hydrochloric acid into it; then turn the stopper, *a*, and allow about a table-spoonful of acid to drop from the globe, upon which the gas will be set free, emanating through the holes in C.

Fig. 4.



When a further supply of chlorine is needed, it is merely required to again turn the stopper, and allow more acid to pass into the basin.

Chlorine is extremely irritating, and cannot be used with safety in the sick chamber, as the quantity required to disinfect the room efficiently would be irrespirable. It has, however, proved useful for fumigating houses where epidemics have existed.

Chloride of zinc and the other metallic chlorides absorb ammonia and sulphuretted hydrogen, and are useful as disinfectants of fœcal matter. In the report of the Royal Cattle Plague Commission, 1866, Mr. W. Crookes, F.R.S., states, with regard to them, that "they possess no power to destroy specific infective emanations," and that chloride of lime is "very irritating to the lungs of diseased and convalescent animals."

For the disinfection of textile fabrics they are too corrosive, and being usually acid, destroy it.

Chloride of zinc, in the proportion of 1 part to 300 of water, instantly destroys infusorial life, and when diluted to but 1 part in 1000 of inorganic liquid, will check decomposition for a considerable time.

As aerial disinfectants, the chlorides possess little or no power.

Sulphurous Acid and the Sulphites.—Sulphurous acid has been used from time immemorial as a disinfectant. It is easily prepared by burning sulphur in the air. It has a powerful odour, and even when present in the air in the proportion of 20 parts to 100,000 parts of air, it is irritating to the system; and 4 parts in 10,000 of air render the air irrespirable. A much smaller proportion present is sufficient to destroy vegetable life.

Water absorbs from 40 to 50 times its own bulk of sulphurous acid, and forms with it a powerful disinfectant.

Owing to its irritating property it is impossible to use it as an aerial disinfectant in sick rooms.

The sulphites possess in a marked degree the properties of sulphurous acid.

The metallic sulphates are useful disinfectants, but are useless as aerial disinfectants, being non-volatile.

A solution of 1 part of a metallic sulphate in 250 parts of an organic solution will prevent the manifestation of infusorial life.

One pound dissolved in a gallon of water is a good disinfectant for drains and fœcal matter.

Permanganate of potash is an oxidizing agent, and does not appear to exert much action on vital manifestation, but is active in the destruction of dead organic matter. This property renders it valuable as a means of purifying potable water. It is of no value as an aerial disinfectant.

Charcoal is a powerful disinfectant, and owes its action to its property of condensing upon its surface and within its pores large quantities of vaporous and gaseous matter, which, by the very force of condensation, they bring into contact with the oxygen of the atmosphere, and thus burn up organic miasms by a process of slow combustion. Wood charcoal will absorb about 9 times its volume of oxygen and 90 times its volume of ammonia.

Dr. Stenhouse in 1853 performed a series of experiments, tending to show the relative value of wood, peat, and animal charcoal. Half a gramme of each kind absorbed the undermentioned number of centimètres of different gases:—

Kind of charcoal.	Ammonia.	Hydrochloric acid.	Sulphide of hydrogen.	Carbonic acid	Oxygen.	Sulphurous acid.
Wood,..	98·5	45·0	30·0	14·0	0·8	32·5
Peat,...	96·0	60·0	28·5	10·0	0·6	27·5
Animal..	43·5	—	9·0	5·0	0·5	17·5

It thus appears that wood charcoal possesses the highest absorbent power for ammonia, sulphide of hydrogen, and sulphurous acid; while animal charcoal is decidedly inferior to those of wood and peat as an *absorber* of gases.

Dr. STENHOUSE availed himself of the absorbent property of charcoal in the construction of a respirator which became a sanitary instrument of great value. It consisted, as first constructed, of a hollow case made of fine flexible wire-gauze, about half an inch wide internally, and of sufficient length and breadth, when folded over the lower part of the face, to cover closely either the mouth alone, or if required the lower part of the nose also. The hollow space is filled with coarsely powdered charcoal, and the whole, like the metallic respirator, is fitted to the face and fastened over the head by attachments of ribbon. All the air that enters the lungs must pass through this charcoal sieve, and is thus deprived of the noxious vapours or gases it may contain. After some time the charcoal powder becomes saturated, or too old to act with efficiency, but an ounce of powdered wood charcoal renews it, and the instrument is itself again. Dr. STENHOUSE has also shown that platinized charcoal has a still greater power of oxidation. The form of the respirator has since been materially altered and also reduced in size.

Charcoal is employed largely for water filters, which, with water containing free oxygen or worked intermittently, will purify water from the foulest matters.

Dr. LETHEBY has adopted charcoal filters in the ventilating shafts of the sewers of the city of London. They consist of an iron box, 18 inches deep and 14 inches square, containing a movable frame of six trays or sieves, upon each of which there is a layer of wood charcoal in pieces as large as filberts, and 2 inches deep. After seven years' experience he reports their working as a perfect success.

Disinfecting Stoves.—The following is a description of the disinfecting apparatus in use in Liverpool designed by the late borough engineer, Mr. Newlands, and shown on Disinfectants, Plate I:—

"*a*, court-yard; *b*, keeper's cottage; *c*, yard to cottage; *d*, receiving house for infected clothes; *e*, depository for clothes after they are disinfected; *f*, wash-house; *g*, drying closet; *h*, disinfecting stoves; *i*, boiler; *j*, stoke hole; *k*, heating apparatus; *l*, coals; *m*, ashes; *n*, cold air shaft; *o*, cold air flue; *p*, hot air chamber; *q*, exhaust flue; *r*, chimney shaft; *s*, cistern.

"The plot of land on which the buildings are erected is situate in New Bird Street, with a frontage thereto of 56 feet, and extending backwards to the depth of about 70 feet. They comprise a spacious flagged court-yard, with paved cart way, a residence for the keeper, a well ventilated receiving room for infected clothes, a depository for disinfected clothes, a wash-house for cleansing infected clothing (containing eight washing troughs, supplied by steam from the boiler in the basement), a drying closet opening directly into the wash-house, and a range of disinfecting chambers under the open shed in the court-yard.

"In the basement are the boiler, stoking pit, heating apparatus, and the coal and ash vaults.

"The disinfecting stoves are each 5 feet wide, 7 feet from front to back, and 6 feet 6 inches high to the springing of the arch.

"The walls and vault are built of brickwork, the doors are of wrought iron, fitting tightly into cast-iron frames.

"The floors are formed with double iron gratings, having alternate openings, the under one being constructed so as to slide, to exclude, if desired, the hot air.

"In the arch over the centre of each stove is an opening, containing an iron valve for the escape of foul air into an exhaust flue, which is carried over the top of the stoves into the chimney shaft.

"Within the thickness of the front wall of each stove a thermometer is fixed, protected from contact with the outer air by a thick plate of glass.

"The drying closet in the wash-house is of a similar construction, with the addition of light wrought-iron sliding clothes' horses.

"The heating apparatus is a cast-iron cockle, patented and manufactured by Messrs. Tessimond & Kissack. Two cast-iron smoke-tight flues are connected therewith, which, after forming a coil, are conveyed along the hot chamber under the stoves into the chimney at the opposite end.

"The furnace doors and ash hole are each regulated by means of sliding dampers.

"Cold air is drawn from the atmosphere through a descending shaft, thence along a brick flue, underneath the floors of the stoke hole into a cavity on each side of the cockle, after passing which it is highly heated and conveyed into a chamber extending underneath the whole length of the stoves and drying closet, and from which it is admitted into the stoves through the sliding gratings before mentioned.

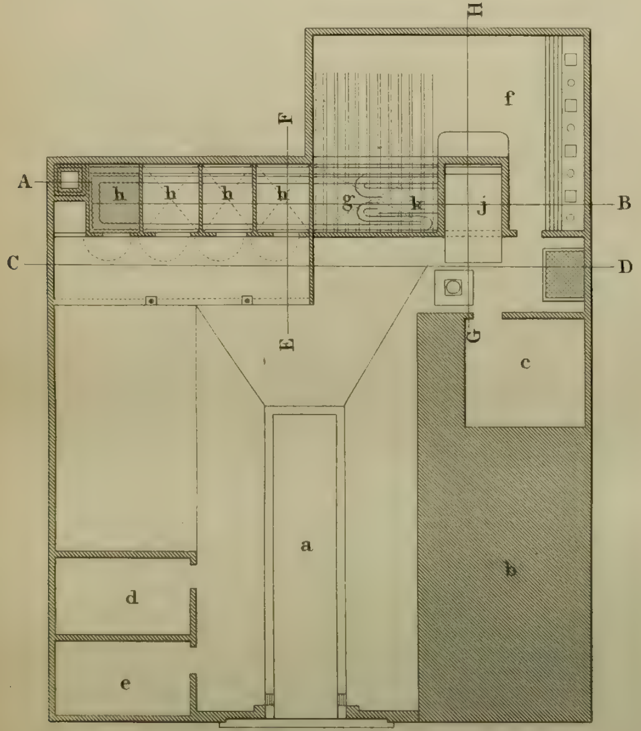
"The temperature of the air is regulated by means of a damper at the entrance to the cold-air flue. As many as 380° Fahr. have been registered in the drying closet over the cockle, and 280° in the stoves."

Dr. TRENCH, the medical officer of health for Liverpool, says they could raise the temperature as high as 500° Fahr.; but that from experience they find that some fabrics are scorched and injured if kept in the chamber for any length of time at any heat above 212° Fahr. He also adds, that in addition to heat, carbolic acid powder is freely sprinkled on the floor of the chamber, so that the vapours reach the articles in the chambers.

The disinfecting stove used in the Royal Victoria Yard, Deptford, consists of a brick chamber with a slightly arched roof, and an iron movable floor in two pieces. The chamber is 7 feet deep, 6 feet 9 inches wide, and 5 feet 8½ inches high in the centre of the arch. It is heated by a flue below the iron floor passing round three sides of the chamber and up a chimney. There is an opening in the upper part of the chamber in its centre which passes along

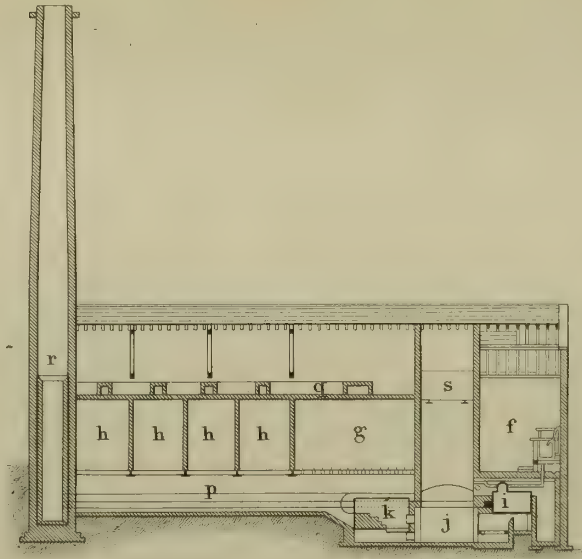
DISINFECTANTS.

DISINFECTING APPARATUS, AT NEW BIRD S^T LIVERPOOL.

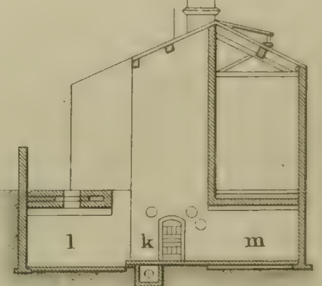


New Bird S^t

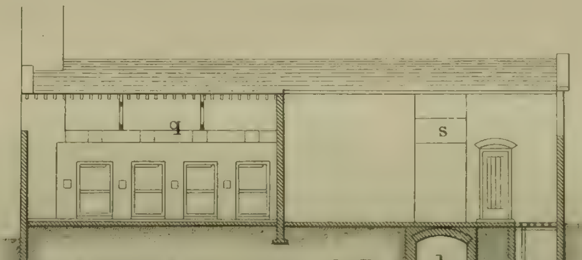
GROUND PLAN.



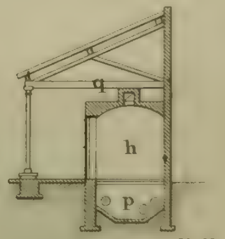
SECTION ON LINE A.B.



SECTION ON LINE G.H.



SECTION ON LINE C.D.



SECTION ON LINE E.F.

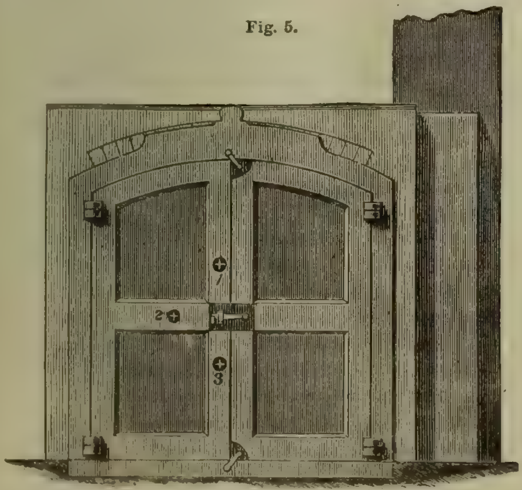
SCALE OF FEET.

in the roof to the side, from thence down in the wall entering beneath the fire; this carries any of the foul air of the clothes from the chamber through the fire and up the flue. This proceeding takes place after the clothes have been in the chamber say an hour and a half in the following manner:—The damper in the foul-air shaft is withdrawn and the furnace door is shut; any draught that gets to the fire comes from the chamber. Over the opening into the furnace is a square opening, fitted with a glass, inside of which is a fixed thermometer. When this shows a temperature of 200° Fahr. the interior of the chamber is at 250° Fahr., the highest point at which it is allowed to be. In the interior of the chamber, at the sides, there are little movable cranes, three rows of three supporting rods of iron on which wooden trays rest, and on which the clothes are placed when the iron cart is not used. The cranes move fore and aft to be out of the way when the cart is used. The cart is of iron on wheels, and runs into the chamber on tramways to keep it in position; in the interior of the cart are three iron trays for laying the clothes on. The lowest tray is always the hottest, so that it is prudent to use the cart, the iron bottom of which prevents burning. The iron ends of the cart are removed when it is placed in the chamber, so is the handle. It is usual to keep the clothes at the temperature of 250° Fahr. for two hours.

There is a trap door 8 inches square about 14 inches above the upper edge of the furnace, and on a level with the iron floor of the chamber, for disinfectants. Carbolic acid and sulphur are used; the former is placed on a flat plate, the latter is sprinkled over the floor. These are used at the last, and after that has been done the clothes are fit to be used without danger to any one.

Elevation plan (Fig. 5) shows the front of the chamber with the doors closed; the openings Nos. 1, 2, and 3 are for inserting the long thermometer, which is pushed into the clothing to be disinfected; they correspond with the three trays.

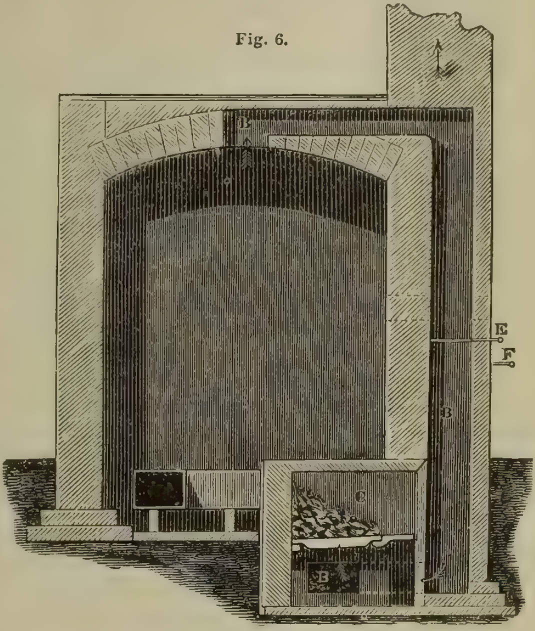
Fig. 5.



The thermometer can be withdrawn and examined without allowing much cold air to enter; plugs fit into these three openings when not used for the thermometer.

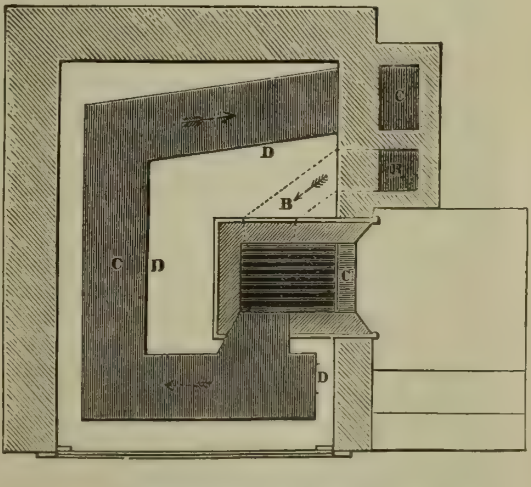
Section (Fig. 6).—The chamber is shown about the centre of its depth; the foul-air shaft B passes along the roof down the side wall and beneath the fire, C; the opening where the fixed thermometer is placed is marked with dotted lines. The damper for the foul-air shaft, E, is represented as shut, and the damper for the chimney, F, is also shut.

Fig. 6.



The *Ground Plan* (Fig. 7) shows the flue beneath the iron plates which form the floor of the chamber, the dotted lines showing the foul air flue, B, as it passes beneath the fire. In the flue, C, there are openings at D D D for the purpose of cleaning it.

Fig. 7.



DYEING AND CALICO PRINTING.—Chemistry of Dyeing and Printing.

General Introduction.—The object of the various processes which are used in dyeing and printing is to impart to a textile fabric a certain colour, and to fix it in such a manner as to make it insoluble in water, and thus prevent it from being removed by washing. This fixation is chiefly effected by chemical reactions, which vary greatly with the nature of the fibre, as well as with that of the colouring matter. In some cases the operations are very simple, and in others highly complicated, several chemical processes taking place either simultaneously or successively.

The animal and vegetable tissues which are used for dyeing differ in their chemical composition as well as in their properties. The principal vegetable fibres are *cotton* and *linen*. In the pure state they consist of a compound called *cellulose*, $C_6H_{10}O_5$, which forms a large proportion of the solid parts of all plants. The pure substance is easily obtained by treating cotton or fine linen with a dilute alkali, dilute acids and ether, which remove all adhering impurities. It is insoluble in water and alcohol, but readily dissolves in an ammoniacal solution of copper oxide (Schweitzer's reagent); on adding an acid to this solution cellulose is precipitated as a white amorphous mass. The cellulose of different plants can be easily distinguished by the microscope, each exhibiting a peculiar structure.

Cotton is the product of different species of *Gossypium* growing in warm countries. The fruit of these plants is a large capsule containing a mass of fine long fibres which envelop the seeds. The microscopic study of cotton is of great interest, offering not only the key to the theory of the fixation of colours, but also the means of distinguishing it from other fibres. According to the late Walter Crum, F.R.S., mature cotton fibre consists of a hollow, shrivelled, irregularly-twisted cylinder, of about $\frac{1}{1000}$th of an inch at its greatest diameter; and if we take middling Orleans at 1¼ inch long, a cord of ⅛ inch diameter and 13 feet long would give an idea of its relative dimensions. It is, however, not of equal thickness. Towards the end farthest from the seed it gradually diminishes, like the tape-worm, to about one-fifth of its greatest diameter, and there its form is more nearly cylindrical and straight. The walls of these tubes do not exhibit openings of any kind which can be taken for lateral passages; but it cannot be doubted that, like other ligneous matter, they are pervious to fluids.

In order to dye cotton the substance to be employed must be in a state of solution, so as to enter the fibre or pass through its pores, and be there made insoluble or precipitated by chemical means. Thus the colour is entrapped within the fibre or its tissue, and becomes fixed there. This is proved by the fact, that on unripe cotton fibre, or *dead* cotton, as it has been called, no colour can be fixed. The unripe fibre consists of very thin and remarkably transparent blades, which are readily distinguishable from those of mature cotton by their perfect flatness, not having the vestige of a cavity even at the sides, being perfectly flat, and broader than the usual fibre.

Strong caustic alkali has a very peculiar effect on cotton. The fibre contracts in length, becomes almost circular, and the cavity shrinks considerably. Mercer has shown that cotton thus treated is stronger, and has a superior attraction for colours, and it was at one time believed that this process, which is called "Mercerising," would yield great results; but unfortunately it has not turned out so useful as was expected, the objections being the large expense of the soda and the great contraction of the fibre, which although making the cloth look finer, is an effect which is more cheaply produced by weaving.

Dr. Schunck has found that cotton in the raw state, as furnished by commerce, contains besides cellulose a certain number of other substances, some of which occur so constantly that they may be considered essential constituents of cotton viewed as a vegetable product. The object of the bleaching process, to which most cotton fabrics are subjected, is to deprive them of the impurities which are either natural to the fibre itself, or have been introduced accidentally or designedly during the process of manufacture. Notwithstanding the importance of an accurate knowledge of everything connected with this staple, from an industrial point of view, the substances existing in cotton fibre have never before the researches of Schunck been subjected to a special chemical examination.

According to Persoz the tissues of cotton, hemp, and linen contain:—

1. A certain quantity of colouring matter, which is more or less protected by the bodies which accompany it, naturally or accidentally.
2. A peculiar resin, insoluble in water, and not easily soluble in alkalies, which plays the part of a resist, and protects the colouring matter inherent to the fibre from the action of the agents which are employed to destroy and remove it.
3. A certain quantity of fatty matter, a very small portion of which is inherent to the fibre, the greatest part being derived from the operations of spinning and weaving.
4. A neutral substance, which consists either of flour, starch, or glue, according as the one or the other has been employed in sizing the warp before weaving.
5. Inorganic salts, some of which are peculiar to the fibre, while the others are derived from the water and the matter used in dressing the warp.

Dr. R. A. Smith says that the substances present in cotton goods, and to be treated in bleaching, are as follows:—*a*, The resinous matter natural to the filaments; *b*, the colouring matter of the plant; *c*, the paste of the weaver; *d*, a fatty matter; *e*, a cupreous soap; *f*, a calcareous soap; *g*, the filth of the hands; *h*, iron rust, earthy matters, and dust; *i*, the cotton fibre itself; *k*, the seed vessels.

The object of the subsequent research of Dr. Schunck was to throw a little more light on the nature of the substances which are contained in or attached to the framework of the cellulose of which cotton fibre mainly consists, and which are, together with the latter, produced by the plant, without taking into consideration the foreign and extraneous matters introduced during the process of manufacture. It is well known that these substances are almost insoluble in water, but soluble in hot alkaline lye. Indeed the principal operation in the bleaching of cotton goods consists in subjecting them for some time to the action of boiling solutions of soda or some other alkali, chlorine or its compounds being only used to impart to them the highest degree of whiteness.

SCHUNCK did not use raw cotton, but cotton-yarn made from definite unmixed kinds of cotton; because it is much freer from mechanical impurities, which are to a great extent removed during, or rather previously to, the operations of spinning; while, on the other hand, in a well-ordered manufactory little or nothing of a foreign nature is added to the cotton to make it impure. Another advantage is, that it is less bulky, and can be more easily worked in such quantities as were required for this investigation. The yarn was exhausted with a solution of soda-ash, and the dark-brown solution precipitated by an acid. The brown precipitate thus obtained from different kinds of cotton amounted to—

	Per cent.
Dhollerah,	0·337
Middling Orleans,	0·480

On burning it left 2·3 to 6·9 per cent. of ash, consisting of oxide of iron, alumina, silicate of alumina, sulphate of soda, and sulphate of lime. The other substances present are—

1. *Cotton wax.*—A body having in its physical and chemical properties, and its composition, the greatest resemblance to vegetable waxes, such as carnauba wax. The cotton wax is undoubtedly identical with PERSOZ'S resin.

2. *Solid fatty acids*, most probably a mixture of palmitic and stearic acids.

3. A colouring matter, easily soluble in alcohol.

4. A colouring matter, sparingly soluble in alcohol. These two colouring matters exist in all kinds of raw cotton; "nankin" cotton differing from white cotton only by containing much more of these colours.

5. *Pectic acid.*

6. *Albuminous matter.*

Linen consists of the fibres of flax and hemp. Under the microscope they appear to be hollow cylinders, which are open at both ends, and provided with knots, which are distributed irregularly over the surface.

Hemp is much coarser than linen, the fibre of the former having a diameter of $\frac{1}{500}$ to $\frac{1}{750}$th of an inch, and that of the latter, $\frac{1}{1000}$ to $\frac{1}{1500}$th of an inch. Linen does not take up colours so readily as cotton, but its attraction for colouring matters is also increased by mercerising.

The most important animal fibres are *wool* and *silk;* both differ from vegetable fibres by containing nitrogen, besides carbon, hydrogen, and oxygen.

Wool has, when purified from the greasy matters and suint, which it naturally contains, the same composition as the so-called albuminous substances, which are such complicated compounds that it has not been possible to assign to them a definite formula. Wool also contains about 2 to 3·5 per cent. of sulphur. The fibre of wool consists of very elastic cylinders, which are covered with scales, and have a diameter of about $\frac{1}{600}$ to $\frac{1}{1600}$th of an inch. Wool readily dissolves in caustic alkalies, and in hot ammoniacal solution of copper oxide, but is not acted upon by the cold liquid. Dilute nitric acid and picric acid impart to it an intensely yellow colour.

Silk.—Raw silk contains naturally a large quantity of gummy substances, which are removed by *scouring* or boiling the silk in soap and water. Silk is the longest fibre known; the thread often exceeds a length of 1300 feet, but having only a diameter of about $\frac{1}{2000}$th of an inch. Under the microscope it appears as a cylindrical fibre, not showing any distinct structure.

It readily dissolves in alkalies, and in a cold solution of an ammoniacal solution of copper oxide. Dilute nitric acid and picric acid colour it yellow.

When raw silk is heated with water under pressure, it yields two distinct compounds, viz.:—

a, *Fibroïn*, $C_{15}H_{23}N_5O_6$, in quantity equal to 66 per cent.; it is a silky glistening substance.

b, *Sericin* or *Silk-gelatin*, $C_{15}H_{25}N_5O_8$, a body resembling gelatin. From its hot aqueous solution it is precipitated by alcohol as a colourless powder, which forms a transparent jelly with cold water.

The fibres of cotton, linen, wool, and silk can be easily distinguished from each other, and detected when they are mixed, by means of the microscope or by the help of chemical reagents.

The appearance of the fibres under the microscope has already been described. If a mixed fabric containing vegetable and animal fibres be treated with strong hot caustic soda, the latter only will dissolve, whilst by the action of dilute nitric acid or a solution of picric acid, and subsequent washing, the vegetable fibres will remain perfectly colourless, and the animal fibre be dyed a permanent yellow. When silk or wool is treated with a hot solution of mercuric nitrate, they take a red colour, while cotton or linen remains white. The latter are strongly attacked and become rotten if moistened with weak hydrochloric acid and dried, while wool and silk remain unchanged. Another very characteristic reaction of wool is, that on moistening it with a solution of lead oxide in caustic soda it blackens, on account of the sulphur contained in it.

Silk is not blackened by an alkaline solution of lead, and is completely soluble in a cold neutral solution of zinc chloride, which does not dissolve wool.

As a general rule animal fibres have a much stronger attraction for colours than vegetable fibres: they take up the colours more readily and hold them more firmly. Not only colouring matters but other substances also are taken up from a solution by the different fibres; such are the different tannic acids and similar substances which are used in dyeing.

The question has often been discussed whether the fibres combine chemically with the colouring matter or not. There is no doubt that a fibre cannot take up more than a certain quantity of a certain colour; but it has never been shown, and it is also very improbable, that a fibre combines with colours in definite atomic proportions, as is the case in true chemical compounds. Moreover, neither the colours nor the fibres lose, in combining, any of their distinct and characteristic properties; and consequently it is possible to remove a colour from a dyed fabric by suitable solvents, and thus obtain the fibre again in its original state.

The great advocate of the chemical theory was the late MICHEL E. CHEVREUL, while WALTER CRUM always maintained that the fixation of all colours was only an attraction of surface resembling that which animal charcoal and other porous bodies exert on colouring matters. At that time the coal-tar colours were not known; these compounds possess the characteristic property of dyeing with the greatest ease, not only all animal fibres, but also bodies having a similar composition, such as skin, albumen, and so on, while they cannot be combined directly with vegetable fibres. From this it would appear, that in dyeing both a chemical and a mechanical action may come into play.

The organic fibres possess also the property of precipitating certain salts or metallic oxides within their tissue. Thus, if cotton be passed through a solution of ferric nitrate, it fixes some oxide of iron, and from an alkaline solution of alum it absorbs the excess of alumina; silk does the same, but its attraction for oxides is much greater, and by passing it repeatedly through a solution of iron or tin salts, and taking care to remove the acid which is set free, a very large quantity of the oxides of these metals may be incorporated into silk. Wool acts in a similar way, and absorbs alum, potassium dichromate, and other salts from their solution.

The different colours which are used in dyeing and printing may be conveniently divided into the following groups:—

I. *Substantive Colours.*—The colours forming this group have the property of combining readily and directly with animal fibre, as well as with substances having a similar composition, such as albumen, casein, skin, hair, &c., but only a few dye directly cotton or linen, and generally produce only very faint shades (*tint shades*); in this case the absorption of the colour is certainly only due to a mere attraction of surface, which is quite similar to that by which certain precipitates, as calcium carbonate, barium sulphate, &c., carry down colouring matters from a solution. However, almost all substantive colours may be fixed on cotton by means of *mordants, i.e.* bodies forming with the colour an insoluble compound, which is precipitated within the fibre. Silk and wool are themselves mordants, or perhaps more probably contain compounds acting as mordants.

II. *Adjective Colours.*—These bodies are like those of the first group, coloured compounds, but differ from them by not being absorbed by animal or vegetable fibres, and therefore dye only by the intervention of a mordant.

III. *Mineral and Pigment Colours.*—These colours are insoluble in water and spirits of wine, and are either precipitated within the tissue by various chemical reactions, or simply fixed by mechanical means. The following list contains a short description of all the more important colouring matters which are employed for dyeing and printing:—

SUBSTANTIVE COLOURS are divided into two groups: (*a*) Such as exist ready formed in nature, and occur chiefly in plants. The most important of these colouring matters are *indigo*, *archil*, *safflower*, and *annotto.* (*b*) Artificial or coal-tar colours.

Natural Substantive Colours.—Indigo, which is one of the most valuable dye-stuffs, is the product of a great number of plants, the most important being different species of *Indigofera*, which belong to the family of *Papilionaceæ*, or the pea family, and are indigenous to India and China, but also grow abundantly in Africa, West Indies, and South America, and are cultivated in all countries where the soil and the climate allow it. The most important are *I. tinctoria*, *I. anil*, *I. argentea*, and *I. disperma*. They grow to a height of 3 to 5 feet, and have a single stem, which ramifies at the upper end and bears pinnate bluish-green leaves.

The round black seeds are sown in India in March or April in a light soil, and the plants are cut or mown towards the end of June or in July, as soon as the first flowers appear. A second and third crop is obtained, but their yield of indigo is less. Of other indigo plants may be mentioned *woad*, or *Isatis tinctoria*, a biennial plant belonging to the cabbage family, or *Cruciferæ*, and growing in Middle Europe; *Polygonum tinctorium*, a native of China; *Marsdenia tinctoria*, *Nerium tinctorium*, *Justicia tinctoria*, and *Asclepias tingens.*

None of these plants contains the colouring matter in the free state, but as a peculiar compound, which SCHUNCK, who first isolated it, has called *Indican.* It is a brown syrupy mass, having a nauseous and bitter taste. By the action of dilute mineral acids it is resolved into *indigotin*, a kind of sugar called *indiglucin*, and other products.

The composition of indican is, according to Dr. SCHUNCK, expressed by the formula $C_{52}H_{62}N_2O_{34}$; and when it is decomposed it is principally resolved into indigo blue and indiglucin, according to the following equation:—

$$C_{52}H_{62}N_2O_{34} + 4H_2O = \overset{\text{Indigotin.}}{C_{16}H_{10}N_2O_2} + \overset{\text{Indiglucin.}}{6\,C_6H_{12}O_6}.$$

Besides the chief products, other bodies are formed: *carbonic acid* escapes, *leucine*, *tyrosine*, and *fatty acids* remain in solution, and *indifuscin*, *indihumin*, *indiretin*, *indifulvin*, and *indirubin*, are precipitated with the indigo blue.

Indigotin, or indigo blue, $C_{16}H_{10}N_2O_2$, forms the blue colouring matter of indigo, which is obtained by macerating the plants with water and a little lime, exposing the liquid in flat vessels to the air, and stirring it up frequently. In the place of lime, ammonia is now used in Java, which is said to give a purer colour. A fermentation soon sets in, by which the indican is decomposed and indigo separates out as a blue powder, which is boiled with water in order to remove a yellow colouring matter, and then pressed and dried. Indigo is found in the market in cubic cakes or in round masses, "fig indigo," which, when rubbed with a hard body, exhibits a copper-red lustre.

Indigo is a mixture of different bodies, containing, besides indigotin, the brown and red colouring matters which have already been mentioned, and inorganic bodies, which on burning are left behind as ash.

According to LEUCHS a certain relation exists between the specific gravity of indigo and the quantity of indigotin contained in it. The more colouring matter it contains the lighter it is, and the determination of its specific gravity may therefore be used as a test for its value. This will be seen from the following table:—

Percentage of indigotin.		Specific gravity.
56-56·5	....	1·324
55	....	1·332
53	....	1·350
49	....	1·371
44	....	1·384
40	....	1·421
37	....	1·437
30·5	....	1·455

This difference in the specific gravities is undoubtedly due to the varying quantities of inorganic matter contained in the different samples, and it has therefore been proposed to test the value of indigo by determining the amount of ash contained in it.

To obtain pure indigotin, indigo is finely powdered and put together with grape sugar and strong soda-lye into a flask, which is completely filled with hot alcohol and well corked. After standing for some time a yellow, clear solution is formed, containing *indigo white* or *hydrindigotin*, $C_{16}H_{12}N_2O_2$, which on adding an acid is precipitated, but in contact with air quickly oxidizes to indigo blue. When the alkaline liquid is exposed to the air it also absorbs oxygen, and indigotin is precipitated. In the place of grape sugar and alcohol, ferrous sulphate and hot water may be used, and the soda may be replaced by lime or any other alkali. As the value of indigo depends only on the amount of indigotin contained in it, this reaction offers a ready means for determining this. JOHN DALE, who has examined this subject very carefully, has found that in this reaction a certain quantity of indigotin undergoes such a change that it is not reprecipitated, and this of course has to be taken into account. His method for testing indigo is the following:—

75 grains of finely powdered indigo are heated with 1 dram of caustic soda of 60° TWADDLE and 5 oz. of water just to the boiling point, and then thrown on a small calico filter and washed with a little water. The filter is then tied up to form a small bag, which is rubbed between the hands in water until the colour is all out of it. 200 grains of ferrous sulphate dissolved in water and 200 grains of freshly-slaked lime are now added, and the whole is made up to 3 quarts, and after being thoroughly mixed a Winchester quart bottle is completely filled with it and tied over with bladder. This must be done with great care, so as to leave no air-bubble in the bottle, which is repeatedly shaken for 12 hours, or better 2 or 3 days, and then allowed to stand until the liquid is quite clear. The bladder is now sliced, and by means of a charged syphon 1 quart is drawn into a measured vessel. To this 1 oz. of acetic acid is added and the whole well stirred. When all the indigotin has separated out, it is collected on a tared filter, washed with warm water, and weighed after drying at 100° C. The weight found multiplied by 4 gives the percentage, to which 4 grains must be added.

Indigotin has a deep blue colour, with a purple tinge, and is insoluble in water, dilute acids, and alkalies; but it dissolves in boiling aniline with a deep blue colour, and in hot paraffin with a purple colour. On cooling these solutions indigotin separates out in small crystals. It is also slightly soluble in boiling alcohol and ether. When indigotin is heated to 300° C. it forms a purple vapour, which condenses in prisms having a purple lustre. When indigotin is treated with oxidizing agents it is converted into *isatin*, $C_{16}H_{10}N_2O_4$, which forms orange crystals.

Indigotin or indigo dissolves in highly concentrated sulphuric acid with a deep blue colour—the first product which is formed being *indigo-monosulphonic* or *indigo-purpuric acid*, $C_{16}H_9N_2O_2(SO_3H)$, which by the further action of sulphuric acid is converted into *indigo-disulphonic* or *indigo-sulphuric acid*, $C_{16}H_8N_2O_2(SO_3H)_2$; generally both are present together in the solution, and can be easily separated by adding water, which precipitates the first of these acids, while the second remains in solution.

Indigo-purpuric acid is almost insoluble in dilute acids, but dissolves in water with a blue colour. With alkalies it forms purple salts, which are sparingly soluble in water. The sodium salt is used for dyeing, and is called *red indigo-carmine* or *indigo-purple*.

Indigo-sulphuric acid forms blue salts. The sodium salt is an amorphous mass, which is known in commerce by the names of *indigo-extract* or *indigo-carmine*.

Indigo-sulphuric acid is converted by oxidizing agents into *isatin-sulphuric* or *isatin-sulphonic acid*, $C_{16}H_8N_2O_4(SO_3H)_2$, which has an orange colour. This reaction may also be used for determining the percentage of indigotin in indigo. The best method, among the many which have been proposed, appears to be that of E. SCHLUMBERGER.

One gramme of indigo is very finely powdered and dissolved at a very gentle heat in 12 grms. of Nordhausen sulphuric acid. All the indigotin is dissolved, while the other organic matters are carbonized. The solution is diluted with water, filtered, and made up to 1 litre. To 100 c.c. of this solution 10 c.c. of hydrochloric acid are added, and the liquid is heated until it begins to boil. Then, by means of a burette, a solution of potassium dichromate containing 7·65 grains in a litre is added until the liquid, which first assumes a greenish colour, changes into a pure orange. Each c.c. of the chrome solution corresponds to 1 per cent. of indigo blue. This method only gives accurate results if care be taken to expel the sulphurous acid formed by the impurities of the indigo.

Among the other substances contained in indigo there is a beautiful purple colouring matter, which, however, is only present in a very small quantity. This compound, which Schunck calls *indigorubin*, has the same composition as indigotin. It sublimes in beautiful purple crystals, and is more freely soluble in alcohol than indigotin. According to Schunck the young plants of *Polygonum tinctorium* do not contain any of it; it can only be obtained from plants which have attained an advanced stage of development, and in the cells of which the indican has already begun to undergo a molecular change. It may, however, be produced artificially by the action of alkalies on indican. Like indigotin it dissolves in alkaline liquids in presence of a reducing agent, forming a yellow solution, from which it is reprecipitated on exposure to the air. If it could be obtained in quantity it would be a most valuable purple colouring matter.

Safflower consists of the petals of *Carthamus tinctorius*, which is cultivated in many parts of Europe, Asia, Egypt, and South America. It contains *carthamin*, or *carthamic acid*, $C_{14}H_{16}O_7$, which is isolated by exhausting safflower with cold acidulated water to dissolve a yellow colouring matter. The residue, after washing, is treated with a dilute solution of soda crystals, and the liquid then precipitated by an acid. A red precipitate is obtained, which fixes itself on cotton thread immersed in the liquid, carthamin having the property of dyeing cotton without the intervention of a mordant, while the yellow colouring matter of safflower is not taken up at all by it. By treating the cotton again with soda-solution the carthamin is dissolved, and on addition of dilute sulphuric or tartaric acid obtained as a red precipitate, drying up to a beetle-green mass. Safflower dyes most delicate rose and pink shades, but unfortunately these colours are very fugitive, and do not stand exposure to the light.

Archil or *Orseille*.—Several lichens (species of *Rocella* and *Lecanora* principally) growing in different parts of the world contain a colourless crystalline compound called *orcin*, $C_7H_8O_2$, or various substances which yield orcin by the action of alkalies. In the presence of ammonia and air, orcin is changed into a true colouring matter called orcein. To this compound the formula $C_7H_7NO_3$ is generally assigned, but by recent researches Liebermann has shown that this body is a mixture of at least two compounds, having the composition $C_{14}H_{13}NO_4$ and $C_{14}H_{12}N_2O_3$.

To obtain the colouring matter the plants are exposed simultaneously to the action of air, ammonia, and moisture, at a moderate temperature, until they have acquired a deep purple colour. Thus a pasty and woody mass is obtained, commercially called *cudbear*. By treating the colouring matter with ammonia, and evaporating the solution to a suitable consistence, impure orcein, known as *archil* or *orseille*, is produced. It dyes on silk and wool a beautiful purple tint; but it is not a fast colour, and is now greatly superseded by the aniline colours.

French purple is a more stable colour. It is produced by exhausting the lichens with cold ammonia, precipitating the solution with hydrochloric acid, and dissolving the washed precipitate again in ammonia. On leaving this solution to stand in the air it soon assumes a cherry-red colour. It is now boiled for some time and then exposed in flat vessels to the air until it assumes a deep purple colour. On adding calcium chloride the purple compound is precipitated, while a red colour remains in solution. The calcium-lake is then decomposed with oxalic acid and the solution evaporated.

Litmus.—This colouring matter is derived from the same lichens which are used in the manufacture of archil. The dried and ground plants are mixed with ammonia and potassium carbonate, and the mixture is left standing until it assumes a violet colour. Then quicklime and urine are added, and the mass allowed to macerate for several weeks. It soon assumes a blue colour, and is then thickened with chalk or plaster of Paris and dried. Litmus is not used in dyeing or printing; its blue colouring matter is the potassium salt of a red acid, which has been obtained in the pure state by exposing an ammoniacal solution of orcin to the air, then adding soda-crystals, and heating the liquid to 60° to 80° C. in contact with the air, until it has changed into blue. On the addition of an acid red flakes are precipitated which do not dissolve freely in water, but readily in an alkali, with a blue colour.

As the value of the different "archil weeds" depends on the quantity of orcin contained in them it is of the greatest importance for the manufacturer of these colours to have a method to determine quickly the percentage of orcin in a sample of these lichens. The old method for doing this is very inexact; it depends on the fact that a solution of orcin is coloured purple by bleaching powder, and the more intensely the more orcin is present. The colour thus produced is very unstable, and soon changes into orange-red and greenish yellow. Reymann has therefore lately proposed the following process for determining the percentage of orcin.

When an excess of bromine water is added to a diluted aqueous solution of orcin it is converted into insoluble tribromorcin, according to the following equation:—

$$C_7H_8O_2 + 6\,Br = C_7H_3Br_3O_2 + 3\,HBr.$$

If, therefore, bromine water of known strength be added to a solution of orcin until no more precipitate is formed, it is easy to calculate the quantity of orcin which is present. To be, however, certain that all the orcin is precipitated, an excess of bromine must be used; and this excess can also be readily determined by adding a standard solution of potassium iodide, and determining the iodine which is set free by means of soda hyposulphite, just in the same way as it is done in the analysis of bleaching powder.

Anotto or *Anotta* is a preparation made from the pulp of the fruit of *Bixa orellana*, a tree growing in Central and Southern America. It contains a yellow compound called *orellin*, and an orange compound called *bixin*, $C_{15}H_{18}O_4$, which is insoluble in water, but readily dissolves in alcohol and alkalies with a deep yellow colour.

Artificial Substantive Colours. — The number of substantive colours which are prepared artificially is much larger than those occurring in nature. They are generally known by the name of *coal-tar colours*, and are all of a very recent origin. Not many years ago coal tar was an almost valueless bye-product in the manufacture of gas, and only of interest to the scientific chemist, who isolated from it a large number of various compounds. This black and fetid substance is, however, to-day employed in huge quantities for the manufacture of colours, which surpass in purity and richness of tint most of the dyes prepared from plants.

The following table gives a complete list of the compounds which so far have been isolated from coal tar:—

I. HYDROCARBONS.

		Boiling point.
Butane or Butyl hydride,....	C_4H_{10}	1°
Pentane or Pentyl hydride, ..	C_5H_{12}	38
Hexane or Hexyl hydride,...	C_6H_{14}	69
Heptane or Heptyle hydride,	C_7H_{16}	99
Octane or Octyl hydride, ...	C_8H_{18}	124
Nonane or Nonyl hydride,...	C_9H_{20}	148
Decane or Decyl hydride,....	$C_{10}H_{22}$	158
Butylene,....................	C_4H_8	1°
Pentylene....................	C_5H_{10}	39
Hexylene,....................	C_6H_{12}	70
Heptylene,....................	C_7H_{14}	100
Octylene,....................	C_8H_{16}	125
Nonylene,....................	C_9H_{18}	149
Decylene,....................	$C_{10}H_{20}$	159

Solid Paraffin.

		Boiling point.	Melting point.
Benzol or Benzene,	C_6H_6	81°	
Toluol or Toluene,	C_7H_8	111	
Isoxylene, ...	C_8H_{10}	138	
Paraxylene,.......	C_8H_{10}	136	
Pseudocumene,....	C_9H_{12}	166	
Mesitylene, ...	C_9H_{12}	163	
Styrolene,........	C_8H_8	146	
Hydronaphthalene,	$C_{10}H_{10}$	210	
Naphthalene, ...	$C_{10}H_8$	217°	80°
Diphenyl,.........	$C_{12}H_{10}$	240	70·5
Acenaphthene,....	$C_{12}H_{10}$	268	95
Phenanthrene, ...	$C_{14}H_{10}$	340	100
Anthracene, ...	$C_{14}H_{10}$	—	213
Pyrene, ...	$C_{16}H_{18}$	—	142
Chrysene, ...	$C_{18}H_{12}$	—	250

II. PHENOLS.

		Boiling point.	Melting point.
Phenol or Carbolic Acid, ...	C_6H_6O	181°·5	42°
Paracresol,........	C_7H_8O	200	35·5
Orthocresol,.......	C_7H_8O	190	—
Phlorol, ...	$C_8H_{10}O$	—	—

III. BASES.

Pyrrol, ...	C_4H_5N	133°	
Aniline,...........	C_6H_7N	181	
Pyridine,.........	C_5H_5N	117	
Picoline,..........	C_6H_7N	134	
Lutidine,..........	C_7H_9N	154	
Collidine,.........	$C_8H_{11}N$	176	
Leucoline,.........	C_9H_7N	238	
Iridoline,..........	$C_{10}H_9N$	—	
Cryptidine,........	$C_{11}H_{1}N$	—	
Acridine, ...	$C_{12}H_9N$	—	107°
Carbazol, ...	$C_{12}H_9N$	354	238

Of this large list of compounds only a few are used for the manufacture of colours, which are conveniently divided into two groups:

(1) Colours derived from bases, or Aniline colours.

(2) Phenol colours.

Colours derived from Bases, or Aniline Colours.—In the year 1826 UNVERDORBEN, a German chemist, discovered among the products of the destructive distillation of indigo an oily basic compound, which readily combines with acids, forming salts, which crystallize very readily and well, and therefore he called this compound *crystalline*. A few years afterwards another distinguished German chemist, Professor RUNGE, who was a great authority in the chemistry of colouring matters, found in coal tar a body which readily forms with acids crystalline salts, and possesses the property of imparting to a solution of bleaching powder a beautiful purple colour. He therefore designated it by the name of *cyanol*, or blue oil.

Somewhat later FRITZSCHE investigated the products which are produced by distilling indigo with potash, and observed among them a large quantity of a basic oily compound, which he analyzed and called *aniline*, from "anil," the Arabic name of indigo, and which means "the blue." About the same time ZININ found that benzene (or benzol, a hydrocarbon which was discovered by FARADAY and which MITSCHERLICH obtained from benzoic acid), could be converted by certain reactions (see ANILINE, page 205), into a basic compound, to which he gave the name of *benzidame*.

Subsequently A. W. HOFMANN found, while working in Professor LIEBIG'S laboratory, that *crystalline*, *cyanol*, *aniline*, and *benzidame* were identically the same substance, which henceforth was known by the name of aniline. FRITZSCHE had already observed that this body produced, with a solution of chromic acid, a blackish-blue precipitate; and BEISSENHIRTZ, in 1853, found that when aniline is mixed with sulphuric acid and potassium dichromate a deep blue colour is produced.

These different observations were turned into practical account in 1856 by W. H. PERKIN, who was the first to elicit the industrial value of aniline, which hitherto possessed only an interest for the scientific chemist. The so-called aniline colours are, however, not prepared from aniline alone, since in most cases two other bases, toluidine and pseudotoluidine, which are nearly related to aniline, are required for their preparation.

Aniline exists in coal tar only in a very small quantity, but, fortunately, it can be obtained indirectly from tar in any desired quantity; and it is now manufactured on a very large scale from benzene or benzol, C_6H_6, which, as HOFMANN was the first to show, exists in light coal-tar oils.

Aniline Purple or Mauve.—This is the colour discovered by PERKINS, who obtained it by mixing cold dilute solutions of aniline sulphate and potassium dichromate. A black precipitate is formed on standing, containing only a few per cent. of mauve, which may be extracted by alcohol.

Although mauve is the most stable of the aniline colours, it is very expensive, and is now almost completely superseded by other aniline violets, which are much brighter and cheaper, though they are also much more fugitive.

Rosaniline or aniline-red is also known by the names of *fuchsine*, *magenta*, *solferino*, *azelaïne*, and *roseine*. Professor HOFMANN observed in 1843, while studying the action of fuming nitric acid on aniline, that a deep red colour was produced; but it was only in 1858 that the formation of a *crimson colouring* principle, and some of its characteristic properties, were first definitely pointed out by him. He, in studying the action of carbon tetrachloride on aniline, observed and described the formation of a basic substance, which dissolved in alcohol with a magnificent rich crimson colour.

The industrial discovery of aniline-red was made in 1859 by VERGUIN and RENARD BROTHERS of Lyons, who obtained it by the action of tin tetrachloride on aniline, and were the first to point out the importance of aniline-red for dyeing and printing, and to show that, by means of this colour, it was possible to obtain tints of a richness and purity superior to all that had been previously produced. They gave to their new colour the name of *fuchsine*, because it resembles that of the flower of the fuchsia.

Soon chemists found out that the formation of this colour was due to an oxidation of aniline, and many other processes were soon patented, the oxidizing agents being mercuric chloride or nitrate, lead nitrate, ferric sulphate, &c.

All these different agents were, however, soon superseded by the use of arsenic acid, which was patented by Dr. MEDLOCK in 1860.

The commercial product contains generally more or less of some violet colours; that which is quite free from it is called *roseine*.

The residues obtained in the manufacture of rosaniline are used for producing cheap red, purple, or brown colours, known as *cerise*, *ruby*, *grenade*, &c. They are simply mixtures of the yellow and purple colouring matters, with more or less rosaniline.

It may be stated here that magenta, as well as other aniline colours, are frequently adulterated with sugar. This falsification is easily effected by steeping finely crystallized sugar in an alcoholic solution of magenta, and allowing the alcohol to evaporate. As easily as this is done, so readily is it detected. It is only necessary to wash the suspected crystals with very strong alcohol, which dissolves the colour, and leaves the white sugar crystals behind. When such a mixture is kept in closed vessels for some time it becomes colourless, sugar, being a reducing agent, reduces the rosaniline to *leucaniline*, $C_{20}H_{21}N_3$, a colourless body, which contains 2 atoms of hydrogen more than rosaniline, and is readily produced by treating a solution of rosaniline with zinc and a dilute acid.

Magenta is now largely used by the Chinese and Japanese. A manufacturer, some years ago, thought he could increase his profits by sending them the colour adulterated with sugar; but not being aware of the reducing action of sugar, he packed the colour in well-closed tin cases, and was highly surprised when he heard that his goods, when arrived in Hong Kong, consisted of colourless crystals.

Rosaniline forms the starting point of a host of other most beautiful colours. By heating it with the iodides of methyl or ethyl, 1, 2, or 3 atoms of hydrogen are successively replaced by methyl or ethyl, and violet and purple colours are produced, which are known as HOFMANN'S violets. They are distinguished in commerce by the terms R, B, and B B. R is a red violet, consisting chiefly of the hydrochlorides of *methyl-rosaniline*, $C_{20}H_{18}(CH_3)N_3,ClH$, and *dimethyl-rosaniline*, $C_{20}H_{17}(CH_3)_2ClH$; while the bluish violet B contains the hydrochloride of the latter base, and that of *trimethyl-rosaniline*, $C_{20}H_{16}(CH_4)_3ClH$; and B B, which dyes a very blue shade, consists only of the last compound. The so-called *Paris violets* have a similar constitution; they are obtained by the action of oxidizing agents on a mixture of *methyl-aniline*, $C_6H_5NH(CH_3)$, and *dimethyl-aniline*, $C_6H_5N(CH_3)_2$, which are manufactured on a large scale by heating aniline-hydrochloride and methyl-alcohol under a very high pressure.

Aniline Greens.—These beautiful colours belong also to this group. That called *iodine-green* has the composition $C_{20}H_{16}(CH_3)_3N_3(C_6H_2(NO_2)_3O_2$, and occurs generally as a paste, which is sparingly soluble in water. The soluble-green, or methyl green, consists of $C_{20}H_{16}(CH_3)_5N_3I_2 + H_2O + ZnCl_2$, and crystallizes in splendid yellowish-green crystals having a copper-red lustre.

Before the discovery of iodine-green, another aniline-green was and is still used. It is prepared by adding aldehyde to an acid solution of rosaniline, and pouring the blue liquid thus obtained into a boiling solution of sodium thiosulphate (hyposulphite of soda). The *aldehyde-green* thus produced has the composition $C_{22}H_{27}N_3S_2O$.

The history of the discovery of this green is very curious. CHERPIN, a workman in the colour works of M. USÈBE, in Saint Ouen, near Paris, made experiments to fix the very unstable aldehyde-blue on tissues, without, however, succeeding. A friend of his, a photographer, to whom he mentioned it, said to him, "What, you cannot fix a colour; I will tell you how to do it. There is one substance which we use, and which fixes every thing, and that is hyposulphite of soda." CHERPIN took the advice, and to his great astonishment obtained a magnificent green.

Some dyers consider the aldehyde-green to be superior to the other aniline greens. As it is but seldom met with in commerce, we give in the following a practical method for its preparation.

Dissolve 1 lb. of magenta crystals in a mixture of 2 lbs. of concentrated sulphuric acid, and half a pound of water. This mixture is heated in a stoneware or glass vessel in a water bath to 75° C. Then 2 lbs. of good commercial aldehyde are added, and the liquid kept warm until it has assumed a pure blue colour. It is now slowly poured into a boiling solution of 4 lbs. of hyposulphite of soda in 10 gallons of water. When cold, the liquid is filtered, and is now ready for dyeing.

Phenylrosaniline.—When rosaniline is heated with aniline in the presence of benzoic acid, or other organic acids, ammonia is given off, and hydrogen is replaced by the group *phenyl*, C_6H_5.

The salts of *monophenyl rosaniline*, $C_{20}H_{18}(C_6H_5)_2N_3$, dye a reddish-violet, and those of *diphenyl rosaniline*, $C_{20}H_{17}(C_6H_5)N_3$, a bluish violet. The so-called *night blue* consists of a perfectly pure salt of *triphenyl rosaniline*, $C_{20}H_{16}(C_6H_5)_3N_3$; while mixtures of this with the preceding compounds are known by the terms B, B B, B B B and B B B B, the first having the most, and the last the least reddish shade. These compounds are sparingly soluble in water, but freely in alcohol.

Soluble Blues.—When triphenyl rosaniline is dissolved in sulphuric acid, and water is added, a dark blue mass, drying up to grains having a golden lustre, is precipitated. This consists of *triphenyl rosaniline sulphonic acid*, $C_{20}H_{16}(C_6H_5)_2(C_6H_4SO_3H)$, and stands consequently in the same relation to triphenyl rosaniline as sulphopurpuric acid to indigo. Its sodium salt, which forms a grey amorphous mass, dissolving with a beautiful blue colour in water, is found in commerce under the name of *Nicholson's blue*. By the further action of sulphuric acid, other sulpho-acids are formed, occurring as sodium salts in several *soluble aniline blues* or *alkali blues*.

Benzyl-rosaniline.—When a mixture of methyl alcohol, methyl iodide, rosaniline, and benzyl chloride, C_8H_7Cl, which is obtained by the action of chlorine on boiling toluene, is heated to 100° C., the compound $C_{20}H_{16}(C_6H_5CH_2)N_3CH_3I$ is formed, crystallizing in beetle green needles. The salts of this ammonium base dye on silk a rich reddish violet.

Chrysaniline or *Phosphine*, $C_{20}H_{17}N_3$ is a bye-product in the manufacture of rosaniline. It forms yellow crystalline salts, dyeing on silk a deep yellow shade.

Saffranine, $C_{21}H_{20}N_4$.—This body is a derivative of pseudotoluidine, and obtained by treating high-boiling commercial aniline first with nitrous acid, and then with arsenic acid, or other oxidizing agents. The hydrochloride, $C_{21}H_{20}N_4.ClH$, occurs in commerce in the form of a paste or reddish powder; it is very soluble in water, but not in a solution of salt, and dyes on silk most delicate rose-tints. It is therefore largely used as a substitute of safflower. It dissolves in concentrated sulphuric acid with a splendid green colour. On gradually adding water to this solution, the colour changes successively into greenish-blue, blue, purple, violet, and finally into red.

Diphenylamine Blue.—This colour is produced by heating commercial diphenylamine (a mixture of diphenylamine and ditolylamine) with sesquichloride of carbon gradually to 180°.

When methylaniline is heated with aniline hydrochloride under strong pressure, it is converted into *methylphenylaniline*, $(NC_6H_5)_2CH_3$, a liquid which, when heated with sesquichloride of carbon, yields a magnificent purple colouring matter.

Phenylene Brown.—This compound, which is also called *Manchester brown* and *Bismarck brown*, is the hydrochloride of triamidoazobenzene, $C_{12}H_{13}N_5$. It is obtained by heating benzene with a mixture of nitric and sulphuric acids, which convert it into solid, crystalline *dinitrobenzene*, $C_6H_4(NO_2)_2$. By acting on this body with tin or zinc and hydrochloric acid it is reduced to *diamidobenzene* or *phenylenediamine*, $C_6H_4(NH_2)_2$, which is dissolved in hydrochloric acid, and then acted upon by sodium nitrite.

$$2C_6H_8N_2 + NO_2H = C_{12}H_{13}N_5 + 2H_2O.$$

Phenylene brown is chiefly used for dying a rich brown on wool and silk.

Magdala red, *Naphthalene red*, is the hydrochloride of the base, $C_{30}H_{21}N_3$, and is obtained from naphthalene, $C_{10}H_8$, a hydrocarbon which exists in a large quantity in coal tar. Nitric acid converts it into *nitronaphthalene*, $C_{10}H_7NO_2$, which is easily transformed into *amido-naphthalene* or *naphthylamine*, $C_{10}H_7NH_2$, by the same reactions by which aniline is obtained from nitrobenzene. It forms crystalline salts, yielding with oxidizing agents a blue precipitate, which soon changes into a purple powder of *oxynaphthylamine*, $C_{10}H_7ONH_2$. On adding sodium nitrite to a solution of naphthylamine hydrochloride a crystalline precipitate of *amidoazonaphthalene*, $C_{20}H_{15}N_3$, is formed. This compound crystallizes in yellow needles, and dyes on silk a fine orange, and forms salts with acids, having an intensely purple colour, but they are very unstable. Thus, on dipping silk which is dyed with the base in hydrochloric acid it turns purple, but on washing with water becomes again orange. When amidoazonaphthalene is heated with naphthylamine Magdala red is produced. It dissolves in alcohol and water with a red colour, and the dilute alcoholic solution exhibits a splendid garnet-red fluorescence. It dyes on silk and wool a delicate red, showing the same fluorescence as the alcoholic solution.

Phenol Colours.—*Phenol* or *Carbolic Acid*, C_6H_6O, occurs in large quantities in coal tar, and is the type of a group of compounds which, like aniline and its homologous bases, are nearly allied to the different hydrocarbons existing in tar. The following coloured derivatives of phenols are used in dyeing:—

Picric Acid or *Trinitrophenol*, $C_6H_3(NO_2)_3O$, is readily formed by the continued action of nitric acid on phenol and many other bodies, such as indigo, aloes, gum resins, silk, wool, &c. It was formerly prepared from acaroid resin, but is now obtained by dissolving phenol in sulphuric acid, and treating this solution with sodium nitrate or nitric acid. Picric acid crystallizes from hot water in pale-yellow plates, having an intensely bitter taste, and forms salts, which have a yellow or orange colour and are very explosive. When picric acid is dissolved in a warm solution of potassium cyanide an intensely red liquid is obtained, containing the potassium salt of *isopurpuric acid:*

$$C_6H_3N_3O_7 + 3CNK + 2H_2O = C_8H_4N_5O_6K + CO_3K_2 + NH_3.$$

This salt crystallizes in small reddish-brown plates, having a beetle-green lustre. The corresponding free acid is not known, but a number of its salts have been obtained. Thus, on acting on the potassium salt with ammonium chloride, we obtain *ammonium purpurate*, $C_8H_4N_5O_6(NH_4)$, which dissolves in water with beautiful red colour, and is used for dyeing wool and silk. When chloride of barium is added to a solution of one of these salts a vermilion red precipitate of barium isopurpurate is formed.

A compound nearly allied to phenol is cresol, C_7H_8O, which also is found in tar, and yields yellow compounds when treated with nitric acid.

Victoria-yellow or *aniline-orange* consists principally of the sodium salt of a *dinitrocresol*, $C_7H_6(NO_2)_2O_2$. Its preparation is not known. A similar colouring matter consists of the potassium salt of another *dinitrocresol.* It forms red crystals, and was exhibited in Vienna under the name of *gold-yellow.*

Manchester-yellow or *Naphthalene-yellow* consists of the sodium or calcium salts of *dinitronaphthol*, $C_{10}H_6(NO_2)_2O$. This compound, which crystallizes in lemon-yellow needles, and forms salts having a deep-yellow or orange colour, is manufactured by treating a solution of naphthylamine hydrochloride with sodium nitrite, and boiling the product with nitric acid. It crystallizes in lemon-yellow needles. The commercial product consists of the sodium or calcium salt of this body, which is also now manufactured by the following process:—

Equal parts of naphthalene and concentrated sulphuric acid are heated to 100°. Thus *naphthalene sulphonic acid*, $C_{10}H_7SO_3H$, is produced, which by fusing with an alkali is transformed into naphthol, $C_{10}H_8O$;

$$C_{10}H_8SO_3 + 2NaOH = C_{10}H_8O + K_2SO_3 + H_2O.$$

Naphthol is a body resembling phenol, and is converted into naphthalene-yellow by dissolving it in sulphuric acid and adding nitric acid to this solution.

$$C_{10}H_8O + 2NO_3H = C_{10}H_6(NO_2)O + 2H_2O$$

Naphthalene-yellow is a very rich and pure colour, dyeing on silk and wool all shades between lemon-yellow and golden-yellow, without showing that greenish reflection which the yellow produced by picric acid exhibits. Its tinctorial power is also very great, one part being quite sufficient to dye on 200 parts of wool a deep yellow.

Aurin or Yellow Corallin, $C_{20}H_{14}O_3$.—This compound, which is also called *rosolic acid*, and used for dyeing on silk and wool a fine orange, is obtained by heating phenol with sulphuric acid and oxalic acid.

$$3C_6H_6O + 2CO = C_{20}H_{14}O_3 + 2H_2O.$$

The commercial product is a brittle mass, having a beetle-green lustre. In the impure state it appears quite amorphous; but lately a purer product has been brought into the market by Messrs. ROBERTS, DALE, & Co., which is distinctly crystalline. The chemically pure compound is a beautiful substance, forming prisms or needles, having either the colour of chromic acid and a brilliant diamond lustre, or of a darker shade with a blue or greenish-blue reflection. In alkalies it dissolves with a magenta-red colour.

Peonin or *Red Corallin* is obtained by heating aurin with alcoholic ammonia under pressure. It differs from aurin by dyeing a bright red shade. The pure compound crystallizes in small bronze-coloured needles. Its composition is not known.

Azulin or *Azurin* is a blue colouring matter, which is formed by heating aurin with aniline. Its composition is not known, and it is now quite superseded by the aniline-blues.

Eosin is a colouring matter having very great resemblance to Magdala-red, but its constitution is quite different. The commercial product is a brown crystalline powder, dissolving in water with a red colour, and exhibiting a splendid greenish fluorescence. It dyes on silk a most delicate pink, showing a rich scarlet fluorescence. Its composition is $C_{20}H_6Br_4O_5K_2$, being the potassium salt of *tetrabromofluorescein.*

Fluorescein was discovered by Professor BAEYER. It is obtained from resorcin, $C_6H_6O_2$, a body which is very nearly allied to common phenol, as well as to orcin, $C_7H_8O_2$ (see *Archil*). On heating this compound with *phthalic acid*, $C_8H_6O_4$ (a product of the oxidation of naphthalene), fluorescein is formed according to the equation—

$$2\ {}_6H_6O_2 + C_8H_6O_4 = C_{20}H_{12}O_5 + 3H_2O.$$

Fluorescein forms small brown crystals, dissolving in ammonia with a red colour. This solution exhibits, even if very dilute, a splendid green fluorescence. By acting with bromine on it the tetra-bromo compound is formed, yielding with alkalies red salts. The name eosin is derived from Ἕως, "aurora." When an aqueous solution of eosin is heated with sodium amalgam it becomes colourless; on adding now one or two drops of a solution of potassium permanganate the liquid becomes deep-green and apparently opaque, but on pouring it into a large quantity of water a solution is obtained having a reddish colour and exhibiting a most beautiful green fluorescence, being due to the formation of fluorescein.

Aloës-purple.—When aloës is heated with nitric acid it is first converted into *aloëtic acid*, $C_{14}H_4(NO_2)_4O_2$, which, by the further action of the acid, is oxidized to *chrysammic acid*, $C_{14}H_4(NO_2)_4O_4$.

Aloëtic acid is a crystalline orange-yellow powder, forming red coloured salts, which are explosive.

Chrysammic Acid crystallizes in small brilliant, golden-yellow plates, dissolving in alcohol or boiling water with a beautiful red colour. Its crystalline salts are very slightly soluble in water and very explosive. They have a red colour, and exhibit a beautiful bronze or beetle-green lustre.

An impure mixture of these two acids is used for dyeing red and brownish-red colours on silk and wool. It has also been applied to cotton as a steam-colour, producing a violet. Mixed with garancin or artificial alizarin, it produces on mordanted cotton garnet-red shades, having a peculiar lustre.

The two acids obtained from aloës are nearly related to the colours contained in madder, and belong to the group of phenol colours.

Murexide, $C_8H_5N_5O_7,NH_3$.—This colouring matter must be mentioned, because it was largely used before the discovery of the aniline colours as a brilliant red dye-stuff. It was discovered in 1835 by LIEBIG and WOHLER, but has been only manufactured and employed in dyeing and printing since 1857. It is obtained from uric acid, a compound existing in the urine of all animals, and found in large quantities in guano, from which it is extracted by treating it with hydrochloric acid, exhausting the residue with hot potash, and adding to the solution thus obtained dilute sulphuric acid, by which the uric acid is precipitated as a white insoluble powder. To convert it into murexide it is dissolved in cold nitric acid, the solution carefully evaporated to dryness, and the residue treated with ammonia, in which it dissolves with a splendid purplish-red colour. The pure compound crystallizes in small red prisms, having a beetle-green lustre, and dissolves readily in water. On silk and wool it dyes a beautiful red colour.

ADJECTIVE COLOURS.—Almost all the colouring matters belonging to this group occur in various plants and animals. Only a very few have been prepared artificially.

Madder is the root of *Rubia tinctorum*, a plant growing in the south of Europe and the Levant. It is largely cultivated in Holland, France, Italy, Southern Prussia, and Turkey. The plant is very nearly allied to the sweet wood-ruff (*Asperula odorata*). It is about three feet high, and has a fibrous root, which is the part used in dyeing. The best roots vary in size between a writing quill and a small finger. They are in the fresh state semi-transparent, of a reddish colour, and possess a peculiar smell. They are collected after two or three years' growth, and dried either in the open air or in stoves. The filaments, and the epidermis (called *mull*), and the pith are removed, leaving nothing but the ligneous fibre. The madder, after being thus purified, is ground in a mill with vertical stones, and then passed through sieves of different fineness. The product thus obtained is distinguished according to its origin into Dutch, Alsatian, Avignon, Naples, Russia, and Turkey madder. Madder is undoubtedly one of the most valuable and interesting dyeing materials, and has been subjected to more chemical researches than any other colouring matter. The discussion on this subject seems to be settled now, it being generally acknowledged that the views of ROBIQUET and SCHUNCK are correct, according to which the finest and most permanent dyes are yielded by *alizarin*, $C_{14}H_8O_4$, while *purpurin*, $C_{14}H_8O_5$, and other coloured compounds contained in the root yield tints of but little stability.

Alizarin, $C_{14}H_8O_4$.—This compound, which has obtained its name from *alizari*, the oriental name of madder, does not exist in the free state in fresh madder, but as a glucoside, called by SCHUNCK *rubianic acid* and by ROCHLEDER *ruberythric acid*, $C_{26}H\ _8O_{14}$. This body, which also occurs in *Morinda citrifolia*, is obtained by exhausting the fresh root with water, and adding to the solution lead acetate, in order to precipitate several organic acids and other bodies. The filtrate yields with basic lead acetate a precipitate of lead rubianate, which is decomposed by sulphuretted hydrogen. On evaporating the solution rubianic acid crystallizes in yellow, glistening, silky needles. It is decomposed by boiling it with dilute acids or alkalies into alizarin and grape sugar, according to the following equation.—

$$C_{26}H_{28}O_{14} + 2H_2O = C_{14}H_8O_4 + 2C_6H_{12}O_6.$$

The same decomposition is produced by the action of a ferment which exists in the root, and has been called by SCHUNCK *erythrozyme*. For this reason madder is only used in dyeing after having been kept for some years, during which an internal fermentation goes on.

Alizarin crystallizes from spirits of wine in yellowish-red needles, containing three molecules of water, which escape at 100° C. On heating it carefully to a higher temperature it sublimes in brilliant red needles, which dissolve but sparingly in water, but freely in alcohol and ether. In ammonia it dissolves with a purple colour, and with potash and soda it yields a solution which in transmitted light appears of a deep bluish purple, and in reflected light of a pure blue. When a solution of the chlorides of barium or calcium is added to an ammoniacal solution of alizarin, or to a solution which has been prepared by boiling an excess of alizarin with a caustic lye, blue precipitates are obtained, having the composition $C_{14}H_6O_4Ba$, or $C_{14}H_6O_4Ca$. Aluminium acetate (red liquor) produces in the alkaline solution a red precipitate, and ferrous acetate or other iron salts give a dark blackish-violet precipitate. When copper acetate is added to an alcoholic solution of alizarin a characteristic purple precipitate is formed. The property of alizarin to form insoluble coloured metallic compounds is made use of in dyeing and printing, as we shall see farther on.

Purpurin, $C_{14}H_8O_5$, crystallizes from alcohol in yellow needles, and sublimes on heating in red needles, dissolving in alkalies with a dark red colour. These solutions yield purple precipitates, with calcium and barium salts.

Purpurin has been produced artificially by heating alizarin with sulphuric acid and manganese dioxide.

Pseudo-purpurin, $C_{14}H_{18}O_6$, is another colouring matter existing in madder root. It is a very unstable body, which is very easily transformed into purpurin.

Besides these compounds madder contains a number of orange and brown colouring matters, citric acid, oxalic acid, pectic acid, fats, resins, gums, and other bodies.

Alizarin is now prepared artificially on a very large scale. Before, however, entering into this subject, it will be convenient to describe first some improvements in the treatment of madder, which have been successively introduced of late years, and which are all directed to the purification of madder. These processes have become more or less obsolete since the discovery of artificial alizarin.

The object of all the different processes is to free the alizarin and purpurin as much as possible from the other bodies found in the root, for the more of these that are removed the easier and the more rapid is the process of dyeing, and the purer and richer are the colours. The portion of the cloth which is to remain white is also less liable to be soiled, and thus the printed goods require less clearing, which always, to some extent, affects the colours.

Garancin was first prepared by LAGIER, ROBIQUET, and COLIN, by treating ground madder for some time with less than one-third of its weight of concentrated sulphuric acid; then water is added, and the mixture is boiled. The product is washed, dried, and ground with some chalk or sodium carbonate, to neutralize any free acid which may be retained by the fibre as well as the pectic acid, which has been set at liberty, and which can only be removed by continued washing with water.

Pincoffin, which was first brought into the market by Messrs. PINCOFFS & CO., Manchester, is a kind of garancin, which is prepared and washed with very great care, and heated with high-pressure steam. Pincoffin yields very bright colours, and especially very pure lilacs.

Flower of Madder (*Fleur de Garance*) is obtained by steeping finely-ground madder-root in acidulated water, and then washing with water and pressing and drying the residue. The product is free from calcium carbonate, gum, sugar, and the yellow and brown colouring matters.

Madder Extracts.—The preparations which have just been described contain more or less of the woody fibre, which, of course, increases the expense of carriage. Therefore, attempts have been made to get rid of these impurities, and to prepare an extract of the root, consisting chiefly of more or less pure alizarin and purpurin. The manufacture of the extracts has been carried on on a large scale, but during the last few years they have been almost completely superseded by artificial alizarin. It will, therefore, only be necessary to give the outlines of the more important processes for obtaining these extracts, which are not obtained directly from madder, but from garancin and other similar preparations.

Alkali Process.—Madder, or one of its preparations, is exhausted with dilute ammonia or soda, the solution precipitated with sulphuric acid, and the precipitate, after washing, is boiled with dilute sulphuric acid.

Spirit-extract is obtained by exhausting flowers of madder or garancin with wood-spirit or common spirit, and distilling the spirit from the solution.

Extraction of Alizarin from Madder.—Fresh madder root, in which the rubianic acid is not yet altered, is ground and treated with an aqueous solution of sulphurous acid, which prevents fermentation of the rubianic acid. The liquid is then filtered, the residue pressed, and the solution mixed with 3 per cent. of sulphuric acid of 1·52 spec. grav. On heating to 30° to 40° C. purpurin separates in red flakes, which are separated by filtration. The filtrate yields on boiling a precipitate of alizarin, which, owing to the presence of an impurity, has a greenish-black colour.

Preparation of Artificial Alizarin.—GRAEBE and LIEBERMANN discovered in the year 1868 that alizarin stands in a very close relation to *anthracene*, $C_{14}H_{10}$, a solid hydrocarbon contained in coal tar. They succeeded not only in reducing alizarin to anthracene, but also in converting the latter into the colouring matter. ANDERSON had already found that when anthracene is heated with nitric acid it is oxidized to a yellow crystalline body, which he called *oxyanthracene*, $C_{14}H_8O_2$, and which is now known as *anthraquinone*. On heating this body with bromine it yields *dibromanthraquinone*, $C_{14}H_6Br_2O_2$, and on melting this with caustic potash, it is converted into alizarin according to the following equation—

$$C_{14}H_6Br_2O_2 + 2KOH = C_{14}H_8O_4 + 2KBr.$$

This discovery would, however, have been but of little practical value, if GRAEBE and LIEBERMANN had not succeeded in replacing the bromine by cheaper materials. (See page 513.)

Artificial alizarin occurs in commerce in the form of yellow or brown paste, containing besides alizarin and water several other products. Of these, however, only one is of practical value. It was discovered by PERKIN, who calls it *anthrapurpurin*, $C_{14}H_8O_5$, having the same composition as purpurin, but quite different properties. In the pure state it forms minute orange needles, and yielding with the alkalies, &c., reactions very similar to those of alizarin. It has about the same affinity for mordants as alizarin, giving similar shades, but the reds are much brighter and purer, the purples more blue, and the blacks more intense. When artificial alizarin first appeared in the market, printers found it very difficult to produce always the same shades, which was owing to the fact that it contained alizarin and anthrapurpurin in varying proportions. This difficulty has now been removed, by separating the colouring matters as much as possible; that consisting of almost pure alizarin, which dyes a bluish-red, being called "blue alizarin," while anthrapurpurin goes by the name of "red alizarin." GRAEBE and LIEBERMANN's discovery forms an epoch in the history of organic chemistry, alizarin being the first natural dye-stuff which has been prepared artificially. Since that time the manufacture of alizarin from anthracene has assumed large dimensions. According to the official report on the Vienna exhibition of 1873, there existed already in Germany ten to twelve such works, while England and France possessed, on account of the patent-laws, each only one alizarin works. The total quantity of alizarin which was manufactured in 1873 was 22,000 cwts. of alizarin paste, containing 10 per cent. of colouring matter, and representing a value of £600,000; while the total amount of madder which hitherto has been used per annum may be estimated at 1,000,000 cwts., with a value of about £2,000,000. It can fairly be assumed that there exists in coal tar a quantity of anthracene which is more than sufficient to manufacture all the alizarin which is contained in the above quantity of madder. This fact is from a politic-economic point of view of the highest importance, for the growth of madder requires a rich soil and occupies several years. For the benefit of mankind this land would be much better employed for the growth of cereals.

Munjeet or *Indian madder* consists of the stems of *Rubia munjista*. It contains no alizarin, but purpurin and *munjistin*, both having probably the same composition. Munjistin crystallizes in yellow plates, dissolving in alkalies with a crimson colour. It dyes on an alum-mordant an orange, and on an iron-mordant a brownish purple.

Brazil wood, *Lima wood*, *Peach wood*, &c., are derived from different species of *Cæsalpinia* growing in South and Central America; while *Sapan wood* comes from India, Japan, and China. They contain a glucoside which is very little known, being easily resolved into a kind of sugar, and into *brasilin*, $C_{22}H_{20}O_7$, crystallizing from water or alcohol in large yellowish prisms, often found in quantity in the extract of the above woods when prepared on a large scale. Brasilin dissolves in alkalies with a crimson colour. This solution gives with aluminium salts and stannic salts a blackish violet precipitate. When nitric acid is added to a solution of brasilin a red crystalline body called *brasilein* $(C_{22}H_{19}O_7)_3N$, is formed. The same oxidation takes place slowly in the air in the presence of ammonia, and therefore an aqueous solution of brasilin, which when freshly prepared is almost colourless, assumes on standing a yellowish-red colour.

Logwood or *Campeachy wood* is the wood of *Hæmatoxylon campechianum*, a tree occurring in South and Central America. It contains *hæmatoxylin*, crystallizing from water in large yellow prisms, consisting of $C_{16}H_{14}O_6 + 3\,H_2O$, and having a sweet taste. When perfectly pure it forms with bases colourless salts, which, however, in the presence of air and ammonia colour red or purple. The coloured compound thus formed has been called *hæmatein* $(C_{16}H_{13}O_6)_3N$, and is also produced by adding fuming nitric acid to a solution of hæmatoxylin in ether. It forms brownish-red crystals, having a green lustre. Hæmatein exists also in the free state in the wood, and a decoction of it gives, therefore, the following reactions.

Alkalies change it first into red and then into violet.

Baryta and lime give blue precipitates, and ferric salts a bluish-black precipitate. Stannous chloride produces a violet precipitate; and an alkaline solution of alumina gives an abundant bluish-violet precipitate. This latter reaction is very characteristic, and serves to detect easily the presence of logwood in a mixture.

Red Sanders Wood or *Santal Wood* is obtained from *Pterocarpus santalinus*, a small tree growing in southern India. It contains *santalin*, $C_{15}H_{14}O_5$, forming microscopic red crystals, which are insoluble in water, but dissolve in alcohol with a red and in alkalies with a violet colour. Similar woods are *camwood* and *barwood*, which comes from *Baphia nitida*, a tree growing in Sierra Leone.

Cochineal consists of the dried bodies of a small insect, *Coccus cacti*, belonging to the family of the gall insects, living on a species of cactus in Mexico and Central America, but now also cultivated in the Canaries, Java, Algiers, and Spain. The colouring matter of cochineal is *carminic acid*, $C_{17}H_{18}O_{10}$, and is prepared by exhausting cochineal with boiling water, and precipitating the solution with lead acetate. The precipitate after being washed is decomposed with sulphuretted hydrogen, and the filtrate evaporated at a low temperature. Carminic acid is a brownish-purple powder, and forms red or purple salts. (See p. 535.)

The splendid pigment "carmine" is obtained by boiling cochineal with water and alum, and leaving the solution to stand. Carmine is gradually precipitated as a fine powder; its chemical nature is not understood; it generally contains alumina, which, however, is not essential to it, the colouring matter being completely soluble in ammonia.

Carminic acid or compounds of very similar properties exist also in the following drugs:—

Kermes consists of the bodies of *Coccus ilicis*, living in south Europe on the leaves of the prickly oak (*Quercus ilicis*).

Lac-dye is the product of *Coccus ficus*, living on the young branches of *Ficus religiosa* and other trees growing in eastern Asia. The insect produces by puncturing the bark an exudation, by which the twigs become incrustate with a brownish-red resin called *stick-lac*. On grinding this product and boiling it with water, *shellac* is left behind; and a solution is obtained, which leaves on evaporation lac-dye, which is found in commerce in the form of small square plates.

Ammoniacal Cochineal.—When carminic acid is treated for some time with ammonia, it is converted into a violet or purple colouring matter. Ammoniacal cochineal is prepared by macerating three parts of ammonia with one part of ground cochineal in a closed vessel during a month. To the clear liquid is then added 0·4 parts of gelatinous alumina, and the mixture evaporated to dryness at a gentle heat. A quicker and apparently a better method is to heat unground cochineal and ammonia together in a closed vessel for eight to ten hours at 100° C., and concentrating the solution by evaporation.

Quercitron is the bark of *Quercus tinctoria* or black oak, which is found abundantly in the southern parts of the United States. It contains *quercitrin*, $C_{33}H_{30}O_7$, which forms small yellow crystals which dissolve but sparingly in water, but readily in alkalies with a greenish yellow colour. When quercitrin is boiled with dilute sulphuric acid it is split up into a kind of sugar, called *isodulcite*, $C_6H_{12}O_5$, and into *quercetin*, $C_{27}H_{28}O_{12}$, which also occurs in other plants. It forms a crystalline lemon-yellow powder, is almost insoluble in water, but dissolves in alkalies with a reddish yellow colour. Its alcoholic solution yields with several metallic salts orange precipitates. *Flavin* is a commercial product which is prepared from quercitron, and is chiefly a mixture of quercitron and quercetin. English flavin appears to consist of almost pure quercetin. There exist several other dye-stuffs which are nearly related to quercitron. Thus the *Chinese berries* or the fruit of *Sophora japonica* contain *melin;* the common garden-rue (*Ruta graveolens*), the leaves of the holly, capers, and buck wheat (*Polygonum fagopyrum*), contain *rutin*, while *robinin* is found in the common white acacia (*Robinia pseud-acacia*). These three compounds have great resemblance to quercitrin, and yield as products of decomposition peculiar kinds of sugar and quercetin.

French and *Persian Berries* are the fruit of *Rhamnus infectoria* and other species of rhamnus growing in different parts of Europe and Asia. They seem to contain different glucosides, yielding as products of decomposition *quercetin* and *rhamnetin*, $C_{12}H_{10}O_5$, which is a body resembling quercetin.

Fustic consists of the wood of *Morus tinctoria*, a tree growing in the West Indies and South America. It contains two distinct colouring matters.

Moritannic acid, or *Maclurin*, $C_{13}H_{16}O_6 + H_2O$, is readily soluble in hot water, and forms yellow crystals. It gives a greenish-black precipitate with ferrous sulphate, and a yellow one with lead acetate.

Morin, $C_{12}H_8O_5$, is only sparingly soluble in water, and crystallizes from alcohol in pale yellow needles, dissolving with a yellow colour in alkalies. This solution gives, with several metallic salts, yellow precipitates.

Weld is the plant *Reseda lutea*, which is cultivated in England, Germany, and France. It is dried entire, and contains a yellow colouring matter, *luteolin*, $C_{12}H_8O_5$, which crystallizes from hot water in fine yellow needles, dissolving with a dark yellow colour in alkalies.

Fustet, or *Young Fustic*, is the wood of *Rhus cotinus*. It contains a yellow colouring matter, but is not much used, because the colours which it dyes are very fugitive.

Turmeric is the root of *Curcuma longa*, a plant which is cultivated in Southern Asia. It contains *curcumin*, $C_{10}H_{10}O_3$, which is insoluble in cold water and sparingly in boiling water, but dissolves freely in alcohol, and forms brilliant yellow crystals. When turmeric paper is moistened with a solution of boric acid and then dried, it assumes an orange colour, which by alkalies is changed into blue. This is caused by the formation of a compound which is called *rosocyanin*. Its composition is unknown. It forms needles showing a beetle-green lustre, and dissolving in alcohol with a splendid red colour, which, on adding a drop of soda, changes into a deep blue. Lime and baryta water give blue precipitates with the alcoholic solution.

Chica, or *Caracuru*, is a red colouring matter, which, like annotto, is used by the Indians in South America for painting their bodies. It is obtained from the leaves of *Bignonia chica*, a large climbing shrub. On boiling the leaves with water, and adding to the decoction the bark of a tree called *Arayane*, a red colouring matter is precipitated. When dry it forms a red mass, which on rubbing assumes a beetle-green lustre. It dissolves in alkalies with an orange colour, and is used for dyeing orange and red shades.

Purree, or *Indian yellow*, is a substance of unknown origin, which is imported from India and China. It consists chiefly of the magnesium salt of *euxanthic acid*, $C_{19}H_{16}O_{10}$. The free acid forms yellow silky crystals, having a sweetish bitter taste.

Chinese green, or *Lo-kao*, occurs in commerce in small scales or plates, having a bluish colour with a green or violet reflection. It is prepared in China from *Rhamnus utilis* and *R. chlorophorus* by exhausting the bark of these shrubs with hot water, and immersing pieces of bleached, but not mordanted, cotton into the infusion. In the evening it is spread on grass, and during the night the upper side colours green. Early in the morning it is removed, dried, and repeatedly treated again as above, until the cloth is super-saturated with the colour. Then it is washed with cold water, and the wash water placed in a boiler and covered with a layer of cotton yarn, from which on boiling the liquid takes up the colour. This process is again repeated, using the same cotton, which when charged with sufficient colour is again washed with cold clear water, and at the same time well beaten or rubbed with the hands to detach the colouring matter, which is collected and dried on paper. From this process it would appear that Lo-kao is the product of oxidation of some colourless compound contained in the plants, and is probably a mixture of a blue and a yellow colouring matter.

Croissant and *Bretonière's New Colours*, which quite recently have appeared in the market, are obtained by fusing sawdust, bran, old paper, or other refuse, with sodium sulphide. They form a black porous mass, possessing a very disagreeable alliaceous odour, and dissolve in hot water with a more or less dark brown or greenish-black colour, and yield with different metallic salts precipitates of various shades. According to the Bulletin of the Industrial Society of Mulhouse, they may be employed for dyeing or printing grey, greyish-brown, yellowish-brown, and yellow shades, which are exceedingly stable and fast. Although such shades can be obtained by the old dyes, they are more expensive and less durable. Owing to the facility with which the new colours can be fixed, it may be expected that they will be used for certain simple goods, of which a great durability in colour is demanded.

Tannic Acids.—The following compounds, thus commonly termed, are a group of colourless bodies existing in several plants, which yield under the influence of a peculiar process of oxidation, or of mordants, brown, grey, or black colouring matter. They are all soluble in water, have an acid reaction, and an astringent taste. They are precipitated from their solution by tartar emetic, salts of tin, and gelatin, and yield with ferric salts bluish-black or dark green precipitates.

Catechu, *Cutch*, or *Terra japonica*, is the extract of the wood of *Acacia catechu*, which grows in India and Burmah, and of *A. suma*, growing in Mysore and Bengal. It contains *catechin* or *catechuic acid*, $C_{13}H_{12}O_5$, in minute acicular crystals, which are sparingly soluble in water. Its aqueous solution gives with ferric chloride a green coloration. When catechin is boiled for some time with water in contact with the air it is converted into catechutannic acid, which also exists ready formed in catechu; it is freely soluble in water, and resembles tannin, from which it differs by yielding with ferric chloride a dark green precipitate. A product analogous to catechu is *Areca-nut catechu*, which is obtained from the seeds of *Areca catechu*, or *Betel nuts*. It does not seem that this body forms a part of the catechu of commerce.

Gambier or *Pale Catechu* is obtained from *Uncaria gambier*, a climbing shrub growing in the countries bordering the Straits of Malacca, and from *U. acida*, which is found in the Malayan islands. Gambier is obtained by boiling the leaves with water, and evaporating the decoction. It contains the same compounds which exist in common catechu.

Kino is the dried juice of *Pterocarpus masurpium*, a tree common in India; it contains *kinotannic acid*, which gives with ferric salts a green precipitate.

Tannin consists chiefly of *gallotannic* or *digallic acid*, $C_{12}H_{20}O_9$, existing in a great number of plants. It is obtained by exhausting nut-galls or Chinese galls either with commercial ether or better with absolute ether containing 5 per cent. of absolute alcohol, and distilling the ether off. It forms a pale yellow amorphous powder, having a very astringent taste. With ferric salts it gives a bluish black precipitate.

The following substances containing tannin are used in dyeing:—

Nut-galls are obtained from *Quercus Lusitanica*, a small kind of oak found in Greece, Asia Minor, and Syria. The tender shoots of this shrub are pierced by the female of a small insect (*Cynips gallae tinctoriae*) which deposits one or more eggs in the puncture. This operation gives rise to a spherical excrescence, known as nut-galls or Aleppo galls. The trade in nut-galls has considerably declined during the last few years, cheaper substitutes, such as sumach, myrobalans, &c., being now largely used in dyeing and printing.

Chinese or *Japanese Galls* are produced by a kind of fly (*Aphis Chinensis*) which punctures the leafstalks and branches of *Rhus semialata*, a small tree indigenous to Northern India, China, and Japan. Chinese galls are of a very irregular shape, and very light and hollow. They contain about 70 per cent. of tannin.

Divi-divi is the flat curved pods of *Caesalpinia coriaria*, a shrub growing in South America. They contain upwards of 50 per cent. of tannin.

Myrobalans are the fruit of different species of *Terminalia*, and chiefly obtained from *T. chebula*, growing in India. The tannin contained in them is, according to Stenhouse, not identical with that existing in galls.

Sumach consists of the powdered leaves and twigs of different species of *Rhus*, and generally obtained from *R. coriaria* or tanner's sumach, a shrub growing in Southern Europe. The best kinds come from Sicily or Spain, the others from Portugal and Italy. Sumach contains only 10 to 16 per cent. of tannin, which is the same as that found in galls.

Besides these drugs, there occur some others in commerce which also contain tannin, but they are of less importance. Amongst these may be named—*valonia*, consisting of the cups of a kind of oak (*Quercus Ægilops*) growing in Southern Europe; *Piedmontese galls* or *Knoppern*, growing on the acorns of *Q pedunculata*; *Pistacia galls* or *Bokhara galls*, found on the leaves of a species of *Pistacia* in Asia; and *Babiah*, the pods of a plant imported from India.

MINERAL AND PIGMENT COLOURS—These colours, which are insoluble in water, are fixed on the fabric either mechanically or by chemical reactions. The fixing of them by mechanical means will be described later on; for the present it will suffice to describe the reactions by which the more important colours of this group are formed. They may be divided into three groups:—

(1) Oxides.
(2) Salts.
(3) Sulphides.

OXIDES.—*Ferric Oxide*, Fe_2O_3, occurs in nature in a more or less pure state, and is obtained as a bye-product in the manufacture of Nordhausen sulphuric acid. Its colour varies from deep red to reddish-brown or brownish-purple. Red ochre is a mixture of clay and ferric oxide. *Ferric hydrate* is obtained as a brown precipitate by adding an alkali to a solution of a ferric salt or a ferrous salt. In the latter case the precipitate consists of ferrous hydrate, which in the pure state is white, but quickly by absorbing oxygen turns green, black, and then brown. The freshly-prepared ferric hydrate is $Fe_2(OH)_6$, but it readily loses water on drying, and is converted into $Fe_2O_3 + Fe_2(OH)_6$. This is also the composition of brown iron-ore and of rust. Yellow and brown ochres are mixtures of clay and the latter compound.

Manganic Oxide, Mn_2O_3.—When manganese sulphate or chloride is precipitated with potash and soda a white precipitate of *manganous hydrate*, $Mn(OH)_2$, is formed, which when exposed to the air quickly absorbs oxygen, and is converted into a deep brown manganic hydrate, which is known as *manganese brown* or *bistre*.

Chromic Oxide, Cr_2O_3.—On adding ammonia, or sodium carbonate, to a solution of green chromic chloride a greenish precipitate of chromic hydrate, $Cr(OH)_6$, is obtained, which on heating loses water, and is converted into the dull green chromic oxide.

A compound of both is *Guignet's green*, which is prepared by heating a mixture of red potassium chromate with boric acid and exhausting the melt with water. It forms a beautiful green powder, consisting chiefly of $Cr_2O_3 + Cr(OH)_6$, but which always contains a certain quantity of boric acid.

SALTS.—*Lead Chromates.*—When a soluble salt of lead (acetate or nitrate) is added to a solution of yellow or red potassium chromate, a yellow precipitate is formed, consisting of *normal lead chromate* (*chrome yellow*), $PbCrO_4$. By acting with alkalies on this compound it loses chromic acid, and changes first into orange and then into a bright orange-red. *Chrome red* is also produced by adding chrome yellow to fused saltpetre; it is thus obtained as a bright red powder, consisting of Pb_2CrO_5 or $CrO_3 + 2PbO$.

Chromic Arsenite.—When precipitated chromic oxide is treated with a solution of sodium arsenite it acquires a bright green colour by combining with arsenious acid.

Copper Arsenite, $CuAs_2O_4$, or *Scheele's Green*, is simply obtained by adding a solution of copper sulphate to a solution of sodium arsenite, which is prepared by dissolving white arsenic (arsenous oxide) in caustic soda, or sodium carbonate.

Emerald Green.—This beautiful colour is a double salt of copper arsenite and acetate, and is readily obtained by boiling concentrated solutions of copper acetate and arsenious acid. A voluminous olive-green precipitate is first obtained, which on boiling is changed into a splendid green. It may also be obtained by boiling SCHEELE'S green with acetic acid. The composition, as well as the shade of this body, varies according to the mode of preparation; but it appears that it principally consists of $Cu_2\begin{cases}(AsO_2)_3\\ C_2H_3O_2\end{cases}$ and is formed according to the following equation:—

$$4CuAsO_4 + 2C_2H_4O_2 = 2Cu_2\begin{cases}(AsO_2)_3\\ C_2H_3O_2\end{cases} + H_2O + As_2O_3.$$

Ultramarine.—This beautiful blue pigment exists in nature as a mineral called *Lazulite*. It is obtained artificially by heating a mixture of China-clay, soda-ash, sulphur, and charcoal. The chemical nature of this body is not satisfactorily understood, and has given rise to almost as many discussions and researches as madder-root. All that is certainly known is, that ultramarine consists principally of a silicate of aluminium and sodium, combined with a sulphide of sodium. By the action of an acid it is decomposed, sulphur and silica separating out, while sulphuretted hydrogen is given off.

Prussian Blue is the compound of a radical which LIEBIG has called *Ferrocyanogen*, $Fe(CN)_6 = Cfy$. When a ferric salt is added to a solution of potassium, ferrocyanide (yellow prussiate of potash), a blue precipitate of *potassium-ferric ferrocyanide*, $Fe_2K_2(Cfy)_2$, is formed. This compound is insoluble in saline solutions, but dissolves freely with a beautiful blue colour in water. It loses its solubility, however, when heated above 110° C. Its aqueous solution is not changed by ferric salts; but by adding ferrous sulphate a deep blue precipitate of *ferrous-ferric ferrocyanide*, $2Fe_2Cfy_3 + Fe_2Cfy$, is produced. This body is the chief constituent of *Prussian blue*, which is prepared by precipitating prussiate of potash with commercial green vitriol (a mixture of ferrous and ferric sulphate), washing the precipitate in contact with air or with chlorine water, and then treating it with dilute hydrochloric acid, in order to remove oxide of iron or basic iron salts. The commercial product always contains potassium, and appears to be a mixture of the two compounds described above. It dissolves in oxalic acid with a fine blue colour. Alkalies destroy the blue colour, an alkaline ferrocyanide and ferric oxide being formed.

When hydrochloric acid is added to a solution of potassium ferrocyanide, a white precipitate of ferrocyanic acid, $CfyH_4 = Fe(CN)_6H_4$, is formed, which when exposed to the air absorbs oxygen with the formation of Prussian blue, while prussic acid escapes:—

$$5Fe(CN)_6H_4 + O = Fe_5(CN)_{12} + 18CNH + H_2O.$$

Turnbull's Blue is obtained as a deep blue precipitate by adding a ferrous salt to a solution of *red prussiate of potash* or *potassium ferricyanide* $K_6(C_{12}N_{12}Fe_2)$. This body is generally regarded as *ferrous ferricyanide*, $Fe_3(C_{12}N_{12}Fe_2)$. It has, however, the same properties and the same composition as Prussian blue, $Fe_5(CN)_{12}$; and there is every reason to believe that both bodies are identical. Its formation can be easily explained:—Ferricyanides are powerful oxidizing agents; thus, in acting on an alkaline solution of manganous oxide, the latter is converted into the peroxide, while the ferricyanide is reduced to a ferrocyanide. From this it appears highly probable, that the first action of potassium ferricyanide on a ferrous salt consists in converting a portion of the latter into a ferric salt. Thus we have now in solution together a ferrocyanide, and ferrous and ferric salts, which act on each other and form Prussian blue:

$$(1)\ K_6(C_{12}N_{12}Fe_2) + 3FeCl_2 + 2HCl = 2HK_3(CN)_6Fe + FeCl_2 + Fe_2Cl_6 + H_2O.$$

$$(2)\ 2HK_3(C_6N_6)Fe + FeCl_2 + Fe_2Cl_6 = Fe_3(C_{12}N_{12})Fe_2 + 6KCl + 2ClH.$$

The peculiar action of stannous salts in modifying the colour of Prussian blue, and producing a rich purplish blue, has never been explained.

SULPHIDES.—These colours have merely a historical interest. Two of them were formerly used in printing.

Arsenic Trisulphide, or *Orpiment*, As_2S_3, is found as a mineral, and is also formed by passing sulphuretted hydrogen through an acid solution of arsenic. It readily dissolves in ammonia; and on exposing this solution to the air, the ammonia volatilizes and orpiment is again deposited, and by this means it may be fixed upon cloth.

Antimony Trisulphide, Sb_2S_3, is obtained as an orange precipitate by acting with sulphuretted hydrogen on an acid solution of antimony. It is readily soluble in alkaline sulphides, and precipitated again by acids. On boiling it with soda and sulphur, and allowing the solution to cool, large yellow crystals of *sodium sulphantimonate*, $Na_3SbS_4 + 9H_2O$, crystallize out. This salt was formerly prepared for use in calico printing. When an acid is added to its solution, or when the latter is exposed to the air, a bright orange precipitate of antimony *pentasulphide*, Sb_2S_5, is obtained. The colour thus fixed on cloth was known by the name of "stinking orange."

MORDANTS.—This term is applied by dyers and printers to certain substances, which form with many colouring matters insoluble compounds. A mordant is in most cases first fixed on the cloth by impregnating the latter with a solution of the mordant, and then rendering the latter insoluble by chemical or physical means. Formerly it was believed that the action was purely mechanical, the mordant having a corrosive or biting action, which served to open the pores of the tissue, and thus allowed the colour to penetrate. From this notion the name was derived—*mordre* meaning, in French, "to bite."

It will not be necessary to describe the different mordants; their nature will be readily understood by remembering the chemical properties of the different colouring matters. It will be sufficient to state, that the mordants which are commonly employed are oxides or basic salts of heavy metals, such as aluminium, iron, tin (all being very weak bases), or compounds of such oxides with tannic acids. The practical dyer and printer uses the term mordant generally in a very indefinite sense, including any substance which facilitates the fixing of a colouring matter: thus, he calls even the solvent of a colour a mordant, if the former be not soluble in water.

In the dyeing of cotton the mordant is in most cases first fixed on the cloth; but as it must not only be deposited on the surface of the cotton, but be also contained in the interior of the fibre, it is first applied in solution, and then rendered insoluble by chemical decomposition.

How this is effected will be best understood by explaining the chemical operations which are employed in calico printing. We will therefore discuss this subject first, although it is much more complicated than that of simple dyeing.

CALICO PRINTING. — The different manipulations and processes of calico printing are almost as varied as the different kinds of patterns which are produced. They may, however, be divided into the following different styles, each of them being quite distinct from the other. By the combination of two or more any kind of pattern, however complicated, may be produced.

1. Dyeing on mordants.
2. Steam printing.
3. Spirit printing.
4. Colours fixed by oxidation.
6. Resist style
7. Discharge style.
8. Chemical printing.
9. Fixing by albumin.

While in dyeing or mordanting the substances are employed in a simple solution in order that they may penetrate the fibre completely, in printing it is required that only certain parts of the cloth shall be impregnated with the colour or mordant. Therefore a mere solution cannot be used for printing patterns, because it would spread out beyond the limits of its application, and this is avoided by the addition of certain substances, which are called *thickenings* or *thickeners*, such as gum or starch, which retain the solution of the mordant or colour within the desired limits.

The principal thickenings are flour, starch, and the different kinds of gum, as well as fats or oils. Mineral matters, such as pipe-clay, china-clay, &c., are also sometimes used for this purpose.

Flour is a mixture of starch and an albuminous substance called *gluten*. When wheaten flour is made into a paste with cold water, and after being tied up in a cloth is washed with water, the starch passes through, and gluten is left as a viscid elastic substance.

Starch or *Amylum* is widely diffused in the vegetable world, being found in nearly every plant. It is most abundant in grain, rice, Indian corn, potatoes; it exists also in large quantity in the stem of several palm trees, &c.

Under the microscope starch is seen to be made up of rounded granules, having an organized structure. The starch-granules of different plants vary much in form and magnitude, and can be easily distinguished from each other. An adulteration of better sorts of starch with cheaper ones can thus be readily detected.

Starch is insoluble in cold water; but heated with it to above 60° C. the granules burst, and a thick mucilaginous mass called starch paste is produced.

British Gum is obtained by heating wheaten starch to 150° C.; it is a white amorphous powder, which is perfectly soluble in water, forming a thick viscid solution. A cheaper sort is *calcined farina*, which is prepared in the same way from potato starch.

Gum Arabic is the product of several species of Acacia, growing in Western Asia, Nubia, Southern Egypt, India, &c., and occurs in commerce under different names, as *Senegal gum*, *Barbary gum*, *Talha gum*, &c.. Natural gum is a compound of *arabin*, $C_6H_{10}O_5$, with potash, lime, and magnesia. Arabin is obtained by dissolving gum arabic in water, and acidulating the solution slightly with hydrochloric acid; on the addition of alcohol, arabin is obtained as a white amorphous precipitate. It may also be prepared by placing an acidulated solution of gum on a dyaliser, when the metallic chlorides will diffuse out, and leave a solution of pure arabin. Arabin having been dried, becomes insoluble even in boiling water, and only swells up. But when an alkali is added, it dissolves like ordinary gum.

Gum Tragacanth is an exudation from the stem of several species of Astragalus—low shrubs resembling our common furze, and growing chiefly in western Asia and Persia. It occurs in mammiform or vermicular masses, swelling up in water to a thick mucilage. So great is its power of absorbing water that, with fifty times its weight it forms a thick mucilage, which will only dissolve in a very large quantity of water. Starch, and the different kinds of gum, have the same percentage composition as cellulose, $C_6H_{10}O_5$.

Dyeing on Mordants.—This kind of work is also called the *madder style*, being chiefly used for madder colours. It may, however, also be applied for other vegetable and animal colours, which are soluble in water, and taken up from their solution by a mordant which has been previously fixed in the cloth. In order that the colours may appear in all their purity, the cloth must be first freed from all foreign matters which it naturally contains, as well as those which are imparted to it by the processes of spinning and weaving.

(1.) The first process to which the grey cloth is subjected is called *singeing*, its object being to remove the nap or the loose fibres on the surface of the cloth. This was formerly effected by drawing the cloth quickly over a red-hot bar of iron or copper; but now it is generally done by passing the cloth over a number of small gas flames, issuing from small holes bored in the upper surface of a hollow cylinder.

(2.) The cloth is next thoroughly wetted with water, which requires some time, because it always contains greasy matters, and therefore throws the water off. This point must be carefully attended to, for if it is not moistened throughout, the operations which follow will not proceed regularly. This second process is called *rot-steep*, because formerly the cloth was steeped in water until the size contained in it began to ferment and putrefy.

(3.) Next follows *liming*, or boiling the cloth in large boilers with milk of lime for twelve or sixteen hours. Thus the fat or grease contained in the cloth is saponified and converted into an insoluble lime-soap. After the cloth being pressed, it is passed through dilute hydrochloric acid, which removes any lime adhering to it, and at the same time decomposes the lime-soap and sets fatty acids free, which are easily removed by the next process.

(4.) After being washed with water the cloth is boiled in a solution of soda-ash and resin-soap. This is called *bowking*, and its object is to remove the fatty acids by converting them into a soluble soap.

(5.) After the cloth has been thus treated, it still contains some of the colour which is natural to it. It is therefore *bleached*, or first steeped in a clear solution of bleaching powder, and then passed through weak hydrochloric or sulphuric acid. After being well washed and dried it is ready for printing.

The mordants for madder-colours are *acetate of aluminium* or *red liquor*, which is obtained by decomposing aluminium sulphate with lead acetate and *ferrous acetate* or *iron liquor*, which is prepared by dissolving iron in pyroligneous acid. The former produces *madder-pinks*, and the latter the *purples* or *lilac*, which are the principal madder colours. Madder yields also strong reds and purplish-blacks by employing the mordants in a more concentrated state, while by using a mixture of them, *chocolates* are produced, which, however, are not in much use, and generally replaced by *catechu-browns*.

Before the mordant is printed on the cloth, it is *thickened* with flour, British gum, &c., to which some *sightening* is added, *i.e.*, a decoction of Brazil wood for the reds, and logwood for lilacs and blacks. By this the pattern on the cloth becomes perceptible, and thus enables the printer to discover any irregularities which may occur. After printing the cloth is dried, and then *aged* or *stored*. The pieces are hung up in a large airy room, which is only warmed in winter. This exposure to the air has the effect of decomposing the mordants, acetic acid escapes, and the oxides of aluminium and iron are precipitated in the fibre. To hasten the process, as far as the iron mordant is concerned, some potassium chlorate is generally added.

The operation which now follows is a very singular one, and is called *dunging* or *cleansing*. The cloth after being printed always contains an excess of mordant which is not fixed, and if after ageing the cloth was immediately dyed, the non-fixed mordant would get loosened, and thus seriously interfere with the dyeing. No clear whites could be obtained, and the purity of the colours would be spoiled by the intermixing of the mordants. The excess of mordant cannot be removed by simply washing with water, because a portion of the fixed mordant would by removal of the thickening also get loose and might be deposited again partially in other parts of the cloth, and therefore the different mordants would again intermix and spoil one another. It is therefore necessary to have a liquid which is capable of removing the thickening and excess of mordant, and at the same time preventing any loose mordant fixing itself on the cloth. A liquid possessing these properties was found to be a mixture of hot water and cows' dung, and is in fact still the best material for this purpose. But besides the unpleasantness of working with such a body, the supply of it has fallen short since calico printing has reached such great dimensions. In certain localities printers had to keep their own cows simply for getting sufficient material. They therefore looked out for substitutes, and found them first in sodium phosphate and other phosphates; for these the arsenite, arsenate, or silicate of sodium, is now employed.

Cleansing plays an important part in dyeing on mordants; the heat of the liquor, as well as its strength, must vary with the different styles, and great care must be taken to have the operation done effectually. Dung substitutes are generally sufficient for iron mordants, but not for alumina; and therefore, in this case, printers generally finish the cleansing by wincing the pieces in cow dung before dyeing.

The action of cow dung has not been clearly explained. It contains a small quantity of alkaline phosphates, besides other salts, and also a peculiar albuminous substance which has been called *bubulin*, and to which some chemists ascribe its specific action.

After cleansing the cloth is washed and is then ready for the dye beck, which is prepared by mixing old ground madder with a sufficient quantity of water, but using not more than is required for the easy running of the pieces through the somewhat gelatinous liquid. If too much water is used, the colour does not fix readily; on the other hand, if the quantity of water is too little, the brown and yellow colouring matters of the root, which are more soluble than alizarin, will be first precipitated by the mordant, and will thus prevent the fixing of the alizarin.

The dye beck is gradually heated to about 40° C., at which temperature the dyeing commences, and then the temperature is gradually raised to 80° C. The whole operation requires about two to three hours; because a certain quantity of alizarin is actually formed during the dyeing process, and further because it is but sparingly soluble in water, and that gone into solution must first be absorbed by the mordant before a fresh quantity can dissolve.

Printers have known for a long time that the brightest madder colours are produced if the water contains some lime. ROSENSTIEHL, who has carefully studied this subject, has found that this is due to the presence of carbonate of lime, which is kept in solution by carbonic acid. But as this gas soon escapes, a lime-lake of alizarin is precipitated. To prevent this, carbonic acid might be passed into the dye beck; this, however, is not convenient when working on a large scale; but the same good results are obtained from calcium acetate, which in the presence of alumina or iron oxide is completely decomposed, and the lime fixed with the colour. Alizarin even decomposes the nitrate and chloride of calcium, which is shown by the fact that by using these salts brighter colours are produced than by dyeing in distilled water alone; morever, the bath becomes acid.

The power of alizarin to decompose salts is also proved by the steam colours, which are produced in presence of acetate, nitrates, chlorides, and sulphates.

Alizarin, which does not saturate mordants in distilled water, will do so completely if one equivalent of calcium acetate is present; but two equivalents give still better results, although one remains undecomposed; while three equivalents are less favourable, although the result is still superior to that produced by calcium carbonate.

Pseudopurpurin, which does not dye in the presence of one equivalent of calcium carbonate, fixes very well if one equivalent of calcium acetate is added; at the same time, some of it is converted into purpurin.

Purpurin saturates the mordants best if two equivalents of calcium acetate be present.

Madder extracts, and the artificial alizarins for red and purple, give the best results with two equivalents of the acetate; the bath is readily exhausted, and remains clearer than in using calcium carbonate.

If the value of madder extract or artificial alizarin has to be determined in the laboratory, it is convenient to use distilled water, to which the required quantity of a standard solution of calcium acetate is added. Certain dye-works, using hard waters, have for a long time improved them by adding acetic acid, which is quite rational. Waters containing large quantities of sulphates, chlorides, or nitrates, are also improved by the addition of calcium acetate, which decomposes these salts; and even sodium acetate may be used for this purpose; but an excess must be avoided, because a hot solution of this salt readily dissolves the colouring matters, and colours like an alkaline solution; but on cooling the colours again separate, showing that the salt is dissociated by heat. Whereas in using water containing calcium carbonate the dye-bath can be used for one operation only, the employment of the acetate allows it to be used for a number of times, if only from time to time equal equivalents of the colour and the acetate be added. At the same time, the colouring matter may be used in excess, and the dyeing will take place at a lower temperature, and more quickly.

The dyed goods are washed and boiled with soap and water to free the colours from the brown and yellow matters which are precipitated, and to clear the whites from any colour deposited on them. This operation is, however, generally not sufficient to get perfectly clear whites, which is effected by *chemicking* or wincing the goods in a dilute solution of bleaching powder, and then washing them carefully.

For very perfect work, in pink and red, some stannous chloride is added to the mordant, in order that any iron salt which may be present be prevented fixing together with the alumina. This solution is called tin-red liquor.

Alumina mordant may also be fixed by printing on the cloth a solution of alum in caustic soda (alkaline aluminate of soda), and then passing it through a solution of sal-ammoniac.

Instead of madder-root, garancin and similar preparations are often used; but lately artificial alizarin is much employed, either by itself or in conjunction with madder.

The following examples will give an idea in what proportions the mordants and thickeners are mixed, in order to produce the different colours or shades. The numbers represent either ounces or fluid ounces for liquids:—

Pinks.

	a.	*b.*
Boiling water,	610	760
Acetic acid, of 11° Twaddle,	30	400
Red liquor,	160	160
Calcined farina,	400	400
Gallipoli oil,	7½	7½
Turpentine oil,	7½	7½

The red liquor for these styles is prepared by treating 62½ parts of alum and 45 of brown sugar of lead with 200 of boiling water.

Reds

	Dark.	Middle.	Light.
Red liquor, of 12° Tw.,	100	100	100
Water,	100	400	1500
Starch,	24	—	—
Calcined farina,	6	200	600
Gallipoli oil,	3	—	—

Lilacs.

	Dark.	Light.
Boiling water,	960	960
Iron liquor, of 14° Tw.,	120	30
British gum,	720	600
Oil of turpentine,	7½	7½

Black.

Water,	240
Iron liquor, of 40° Tw.,	320
Calcined farina,	100
Quercitron liquor, of 27° Tw.,	20
Logwood liquor, of 25° Tw.,	20
Olive oil,	2½

The madder style is not confined to madder only, but there are several other colouring matters which may be applied to cloth in a similar way. The most important of these are:—

Quercitron gives with an alumina mordant a bright yellow, with an iron mordant an olive-grey, and with a mixture of both a number of yellowish olive shades. A good orange is produced by dyeing with a mixture of madder and quercitron on alumina mordants, and thus, by varying the proportions of the two dyestuffs, various shades, from golden-yellow to scarlet, can be produced. By using as mordants different mixtures of red liquor and iron liquor, and dyeing with varying proportions of madder and quercitron, varying brown and fawn shades are obtained.

Logwood produces on iron mordants greys and blacks; and on alumina, violets and purples.

Cochineal yields on alumina a pinkish violet, and together with logwood fine lilacs; cochineal and quercitron dye on the same mordant a beautiful orange.

Besides these examples, a great number of others might be given; for by combining two or more colouring matters, and varying or mixing the mordants, an endless variety of shades can be produced.

STEAM PRINTING.—*(a) Topical Steam Colours.*—This process is much more simple than the madder style. The thickened solution of the colouring matter is mixed with the mordant (when any is required), and printed topically on the cloth. After drying, the colour is fixed by heating the goods.

In this style neither dunging nor subsequent cleaning is required. Since the introduction of madder-extract and artificial alizarin, these substances are largely used in steam printing, by which very bright colours are obtained. The mordants are exactly the same as in the madder style, and are fixed along with the colour by steaming. The changes which take place are very simple; the acetates are decomposed by heat, and the colouring matter dissolves in the acetic acid which is set free. But by the continued action of heat the latter gradually escapes, and then the colour combines with the fixed mordant.

The following are a few recipes for thickenings, mordants, and different steam colours.

Thickenings for Red.

	a	b
Wheat starch,	60	60
Water,	200	170
Acetic acid 8° Tw.	40	170
Gum tragacanth paste of 6 per cent.	100	—
Olive oil,	15	15

Thickening for Violet.

Wheat starch,	50
Water,	180
Gum tragacanth paste of 6 per cent.	90
Acetic acid of 8° Tw.,	30
Olive oil.	10

Solution of Acetate of Alumina.—34 lbs. of alum and 31 lbs. of soda crystals are dissolved, each separately in 40 gals. of water, and the solutions are mixed. The precipitate, consisting of basic sulphate of alumina, is well washed and pressed. 15 lbs. of the paste thus obtained is mixed with 6 lbs. of acetic acid of 11° to 12° Tw., and the mixture heated to 32° C., until the precipitate is dissolved, and then the solution is filtered.

Solution of Nitrate of Alumina.—This mordant, which is also much used for steam colours, is obtained by dissolving 10 lbs. of nitrate of lead, and 10 of alum in 10 gals. of boiling water, allowing the precipitate to settle, and then decanting the clear liquid.

STEAM REDS.

(*a*) 80 oz. of alizarin paste of 15 per cent., or
120 of 10 per cent., are well mixed with
100 fluid oz. of acetic acid of 8° Tw.
200 oz. of water.
20 oz. of olive oil.
20 oz. of acetate of lime of 14° Tw.; and
50 oz. of wheat starch.

The mixture is boiled, and when cold, 20 oz. of acetate of alumina are added.

(*b*) 260 oz. of alizarin paste, 15 per cent.
60 oz. of acetate of alumina, 17° Tw.
30 oz. of nitrate of alumina, 22° Tw.
40 oz. of acetate of lime, 24° Tw.
1000 fluid oz., thickening for red.

(c) *Very dark red.*

360 oz. of alizarin paste.
60 oz. of acetate of alumina
40 oz. of nitrate of alumina.
50 oz. of acetate of lime.
1000 oz. of thickening.

(*d*) *Steam red without oil.*

280 oz. of alizarin paste.
480 oz. of acetic acid, 11° Tw.
180 oz. of farina.
240 oz. of water.

Boil, and add when cold—

48½ oz. of acetate of lime, 22° Tw.
100 oz. of nitrate of alumina, 20° Tw.
150 hyposulphite of lime, 270° Tw.

(e) *Pink.*

160 oz. of alizarin paste.
800 oz. of water.
50 oz. of acetate of alumina, 17° Tw.
25 oz. of acetate of lime, 24° Tw.
2000 to 3000 oz. of thickening.

Lilac.

90 oz. of alizarin paste.
1000 oz. of water.
20 oz. of iron liquor, 17° Tw.
37 oz. of acetate of lime, 22° Tw.

The pieces are well dried, and steamed with moist steam for 1 to 2 hours; then they are aged for a day or two, and now passed during 1 to 2 hours through a bath containing—

100 oz. of water.
2 oz. of chalk.
½ oz. of arsenate of soda.

After washing, the pieces are soaped.

Steam printing was formerly chiefly employed for wood colours, which yield very permanent and brilliant shades.

Before printing, oxide of tin is generally fixed on the cloth by padding it in a solution of sodium stannate, and then passing it through a solution of sal-ammoniac. By the presence of tin oxide the brilliancy of most steam colours is much increased. The mordant which is most frequently used is red liquor, to which some oxalic acid or some other acid is added, to prevent a precipitation of the colouring matter with the mordant. The principal colours obtained in this way are the following:—

Steam red is obtained by using a mixture of decoction of cochineal, stannous chloride, and oxalic acid. The carminate of tin which is thus formed is a very brilliant colour. Cheaper but less brilliant reds are produced by using extract of Brazil wood. The following receipt yields a very good red:—10 lbs. of extract of cochineal, of 6° Tw., are boiled with 1 lb. of starch, and the warm paste is mixed with 3 oz. of oxalic acid and 4 oz. of tin crystals.

Steam yellow is generally produced by employing a decoction or extract of Persian berries; but fustic or quercitron may also be employed, the mordants being red liquor or alum, with some tin crystals.

(*a*) 10 lbs. of extract of quercitron, of 7° Tw., are mixed with a solution of 1 lb. of alum in 2½ lbs. of water, and thickened with 3½ lbs. of gum Senegal.

(*b*) 10 lbs. of extract of Persian berries, standing at 8°, is mixed with 20 oz. of alum, 3 lbs. of gum, and a small quantity of tin crystals.

Steam purple is obtained by using extract of logwood and red liquor.

Steam black is also a logwood colour, a decoction or the extract of this wood being used, mixed with iron liquor, red liquor, and some acetic acid, to which sometimes a little oil is added. The following recipes may serve as examples:—

(*a*) *Black.*

Logwood extract, of 8° Tw., ...	5	lbs.
Acetic acid, ...	1¼	"
Acetate of alumina, of 14° Tw.,..	1¼	"
Iron liquor, of 20° Tw.,.........	1¼	"
Starch, ...	⅜	"

(*b*) *Bluish black.*

Logwood extract, 5° Tw.,.......	2	gals.
Starch,.....	7	lbs.

Boil, and add—

Chlorate of potash,.............	1½	oz.
Pink salt,......................	4	lbs.

(c) *Lilac.*

Logwood extract, 14° Tw.,......	8	gals.
Water, ...	48	"
Gum,...........................	17	lbs.
Alum, ...	4	"
Nitrate of copper, of 78° Tw.,....	¼	"

(*d*) *Grey.*

Logwood extract, 1° to 2° Tw.,..	4	lbs.
Acetic acid, 12° Tw.,...........	4	"
Copperas, 30° Tw., ...	4	"
Gum water, 30° Tw.,............	120	"

Aniline Colours.—Rosaniline and its derivatives are also employed as steam colours. All these bodies form with tannic acid insoluble coloured compounds, and may therefore be fixed by simply printing a mixture of the colour with acetic acid and tannin, and steaming.

The colours thus obtained are very bright, but also very fugitive. They become faster if a metallic oxide, or any substance forming with tannic acid an insoluble compound, be present. The following methods have therefore been proposed:—

(*a*) The steamed goods are passed through a warm solution of tartar emetic (LLOYD & DALE'S patent).

(*b*) The cloth is impregnated before printing with stannic oxide or alumina.

The cloth is printed with tannic acid, and after steaming passed through a solution of gelatin or tartar emetic, and then dried in a bath acidulated with acetic acid.

Soluble aniline-blue or alkali-blue is readily fixed by mixing it with aluminium acetate and steaming the cloth after printing.

Another method for fixing aniline colours, which has come into use lately, has been objected to, because the cloth is impregnated with a considerable quantity of arsenic. Arsenous acid (white arsenic) is dissolved in glycerin, and this solution is mixed with red liquor and the colour. The thickened mixture is printed, dried, and steamed. The mordant in this case is an arsenite of alumina, which is quite insoluble in water.

The process of PERKIN and SCHULTZ is similar and gives excellent results; a good bluish-pink being obtained by printing a thickened mixture of 1 litre of aluminium acetate of 10° B., 80 grammes of sodium arsenite, and 16 grammes of magenta. The pieces are then steamed for an hour, soaped, and well washed. Nearly all the aniline colours may be fixed by this process.

Saffranine may be fixed by boiling a mixture of aluminium acetate 1 gallon, water 1 gallon, and starch 2 lbs.; when cold, 1 pint of arsenic solution is added, and the goods after printing are steamed for half an hour. The solution of aluminium acetate is prepared by dissolving 5 lbs of alum in 2 gallons of water, precipitating with 6 lbs. of lead acetate, and allowing to settle. To obtain the arsenic solution, 4 lbs. of white arsenic is dissolved by heat in 1 gallon of glycerin.

Annotto is also much used for obtaining deep yellow steam colours, which are best produced by the following process:—

13 lbs. of annotto are mixed with 2·4 gals. of spirits of wine of 90 per cent., and 2·4 gals. of boiling water and 1·2 gal. of soda-lye of specific gravity 1·16 are added. The mixture is allowed to stand over night, and the clear liquid is then decanted. The residue is well pressed, and then exhausted with 3·6 gals. of boiling water, and the solution allowed to settle. All the clear liquids thus obtained are mixed and thickened by adding 6 gals. of tragacanth paste, containing 3·5 per cent The goods are printed, steamed, and washed. If lighter shades be required, extract of berries and alumina acetate are added.

Chemical Steam Colours.—The most important colour of this group is *Prussian blue*, which is obtained by means of a mixture of potassium ferrocyanide and an acid such as tartaric, oxalic, or sulphuric acids. The chemical reaction taking place on steaming the goods is very simple: the acid sets free ferrocyanic acid, which, as we have seen, is decomposed by the action of heat and the air into prussic acid and Prussian blue.

Steam Blue.—A solution of 6½ lbs. of yellow prussiate is dissolved in 10 lbs. of water, and mixed with a solution of 3⅓ lbs. of alum, 2½ of oxalic acid, and 2½ of tartaric acid. After adding a little nitrate of iron for "sightening," the mixture is thickened with gum.

A very good *steam green* is obtained by employing a thickened mixture of extract of Persian berries, potassium ferrocyanide, stannous chloride, alum, and oxalic acid. The formation of a green colour under these conditions does not require any further explanation.

By using a combination of the madder style with steam colours, a great variety of colours may be obtained. Thus, a design in black, lilac, pink, green, blue, orange, and yellow, on a white ground, may be obtained by first printing on the cloth two iron liquors of different strength, one for black and the other for lilac, and with red liquor for pink. After being aged and dunged, the cloth is dyed with madder and then printed with the mixture for steam blue and steam yellow, which latter is also printed on a part of the pink to produce orange, while the green results from the mixture of the blue with the yellow.

Spirit Printing.—This style has derived its name from the fact that stannic chloride was the mordant originally employed for this kind of work. Anhydrous stannic chloride is a fuming volatile liquid, and was therefore formerly called *spirits of tin*, or *dyers' spirit*. It is generally prepared by dissolving metallic tin in a mixture of hydrochloric and nitric acid, care being taken to avoid too great an elevation of temperature. The vegetable colours which are applied to the cloth are soluble in a strong solution of the mordant, but precipitated together with the mordant on the addition of water. Therefore, on printing the colour together with the mordant on calico, and then, after being dried in a cool place and passing the pieces through water, the colour is fixed.

At present all fugitive topical colours which are not fixed by steaming are called *spirit or fancy colours*. The following are the more important of this class:—

Spirit Purple.—A decoction or extract of logwood is mixed with tin spirits and starch paste and printed on the cloth, which is dried for two days in a warm room, and then washed. By using peachwood, &c., *spirit pinks* are obtained.

Spirit Purple.—1 gal. of logwood liquor, of 6 Tw., is boiled with 1 lb. of starch, and after it is almost cold it is mixed with 1¼ pint of tin spirits, of 120° Tw., and ¼ pint of oil.

Spirit Pink.—1 gal. peachwood liquor, at 8° Tw., 1¼ lb. starch; boil, and add ¼ pint solution of nitrate of copper, at 100° Tw.; and when the mixture is almost cold, 4 oz. of pink salt, ½ pint of oil, and 1½ pint of spirits of tin are added.

Spirit Yellow is produced by Persian berries, the mordant being either tin spirits only or mixed with alum. A mixture of red liquor and alum may also be used.

Spirit Black.—Extract or a decoction of logwood is mixed with ferric nitrate (pernitrate of iron) and ferrous sulphate or copperas. This mixture thickened with starch may be printed on the cloth at the same time as the mordants for madder style, because after ageing the colour becomes so fast that it is but little affected by the subsequent operations of dunging, dyeing, and clearing.

Examples of Spirit Black.

No. 1.	No. 2.
1 gal. of decoction of logwood, at 7° Tw.	1 gal. of logwood liquor, at 8°.
4 oz. of copperas.	2 oz. of copperas.
1 lb. of pernitrate of iron, at 50° Tw.	1 pint of pernitrate of iron.

Boil the logwood liquor and copperas with 1¼ lb. of starch, and when almost cold add the pernitrate.

A fast black is also obtained by printing with a mixture of logwood extract, red liquor, and oxalic acid, and passing the cloth after ageing through a solution of red potassium chromate. By using more dilute solutions, chocolate or puce colours are produced. This colour is a combination of the colouring matter of logwood (hæmatein) with chromic oxide. These older blacks are now generally superseded by aniline black, which will be described in the following chapter.

Colours fixed by Oxidation.—The most important colours of this style are *catechu brown*, *indigo blue*, and *aniline black*.

Catechu Brown.—Catechu contains no real colouring matter, but under the influence of oxidizing agents it developes a fine and very permanent brown or chocolate, which is often applied in conjunction with madder colours. The mordants for this style are copper salts, the nitrate being chiefly employed, which, while oxidizing the catechu, are reduced to salts of the suboxide. But as the latter are insoluble in water, they would fix on the cloth and thus prevent a complete oxidation. It is therefore essential to keep them in solution, which is easily done, by mixing the copper salt with sal-ammoniac. This mixture is printed together with the madder mordants, the colour being developed by ageing, and not affected by the processes of dunging and clearing.

Bichromate of potash is also frequently used as an oxidizing agent.

(*a*) *Dark Catechu Brown for Madder.*—6 lbs. of catechu are boiled with 1 gal. of water and 1¼ lb. of sal-ammoniac, and to the strained decoction are added 2 gals. of gum water, 2 pints of nitrate of copper of 80°, and 1½ pint of a solution of acetate of copper, which is prepared by dissolving 4 lbs. of sugar of lead, and 4 lbs. of sulphate of copper in one gal. of warm water.

(*b*) *Medium Brown.*—5 lbs. of catechu, 12 oz. of sal-ammoniac, 4 pints of water; boil, strain, and add 1 lb. of acetate of copper, and 1 gal. of gum water.

(*c*) *Chrome Brown.*—6 lbs. of catechu are boiled with 4 lbs. of water and 12 lbs. of acetic acid at 10°; the solution thickened, printed, steamed; and then the cloth is passed through a hot solution of bichromate of potash, containing ½ per cent. of the salt.

INDIGO PRINTING.—The chemical theory of this style is simple enough. Finely ground indigo is mixed with a reducing agent, and the mixture is printed on the cloth, which is dried and then dipped into an alkaline solution. Thus the indigo blue is reduced to soluble indigo white, which penetrates the fibre, and is precipitated by passing the goods through a weak acid. On now exposing them to the air, the indigo white is oxidized again to indigo blue.

The china blue style, which has derived its name from the colour resembling the blue on old china, was formerly always employed to produce two or more different shades on a white ground. This is done by printing a thickened mixture of finely ground indigo and ferrous sulphate or acetate of different strength, and after drying, dipping the cloth alternately (1) into milk of lime; (2) into a solution of ferrous sulphate; (3) into caustic soda. By these operations the blue is gradually reduced and absorbed by the fibre. The ferrous oxide which is produced by the subsequent immersions can only act on the indigo which is on the surface of the cloth, and thus on continuing the dippings, more and more indigo-white is deposited within the fibre. During these operations the whole surface of the cloth becomes coated with oxide of iron, which is removed by dipping in a dilute acid.

The following method is given by THILLAYE.

16 lbs. of indigo, 4 lbs. of orpiment, 22 lbs. of copperas, and 100 lbs. of water are well ground together for three days, the water being added only gradually. This gives an almost black colour; to obtain the different lighter shades, it is mixed with gum water. Thus twelve different shades are obtained by diluting it in the following proportions:—

Volume of normal colour,	1	11	10	8	6	4	2	2	2	2	2	2
Gum water,............	0	1	2	4	6	8	10	12	14	16	18	20

After printing, the cloth is hung in a warm room for two or three days, and then alternately passed through the following solutions.—

(1) *Lime vat*, consisting of 100 lbs. of quicklime in 600 gals. of water.

(2) *Iron vat* is a solution of ferrous sulphate of spec. grav. 1·048.

(3) *Soda vat*, or caustic soda of spec. grav. 1·055.

The pieces are left in each vat for 10 minutes, and are dipped in the following order:—

Lime vat.	Soda vat.	Lime vat.
Iron vat.	Iron vat.	Iron vat
Lime vat.	Lime vat.	Soda vat.
Iron vat.	Iron vat.	

The mixture used by Lancashire printers is different. PARNELL gives the following proportions:—

Indigo, 16 lbs.
Strong iron liquor, from 5 to 6 gals.
Orpiment, 2 lbs.
Gum water, sufficient to make 8 gals.

To obtain the different shades, it is diluted in the following proportions:—

Vol. of normal colour,	1	1	1	1	1	1	1	1	1	1	1
Vol. of gum water,...	0	½	¾	1	2	3	5	7	9	12	16

The part which orpiment (arsenic sulphide) plays in the production of China blue is not known. As it reduces indigo only at a boiling heat, it appears that as good a colour is produced by leaving it out; PERSOZ recommends the following proportions:—

Indigo,.....	17½ lbs.	Gum,........	33 lbs.
Copperas,...	17½ "	Water,......	55 "

Orpiment may, however, also be used without a ferrous salt for producing a good *pencil-blue* by proceeding as follows:—

20 gals. of caustic potash, at 34° Tw.; 12 gals. of finely ground indigo paste, containing 2¼ lbs. per gal., are boiled, and 22 lbs. of orpiment are gradually added. When boiled for an hour, 2 gals. of caustic potash, at 20° Tw., are added; and after standing for two hours, the clear liquid is thickened with gum Senegal and a little oil of turpentine.

Instead of using a ferrous salt or orpiment, zinc dust, finely-powdered tin, or stannous oxide, may be used as reducing agents.

A different method of indigo printing is the following:—

Finely ground indigo is reduced by heating it with caustic soda and tin crystals. On adding hydrochloric acid to the solution, a compound of indigo white and stannous oxide is precipitated. This *indigo precipitate* must be quickly washed and thickened. On dipping the cloth in milk of lime, indigo white is set free and fixed by exposure to the air, and dipping in dilute sulphuric acid to remove the lime. A fast green is obtained by adding to the mixture a soluble lead salt; which is first converted into the oxide, and then into the sulphate. It is now only required to pass the cloth through potassium chromate to obtain the desired green.

Another powerful deoxidizing agent, which has lately come into use for indigo printing, is sodium hydrosulphite, HNa_2SO_3. This salt, which is obtained by the action of zinc on a solution of acid sodium sulphite, reduces indigo blue rapidly in the cold to indigo white, which dissolves in presence of an alkali. The thickened solution is printed on the cloth, and the colour developed by exposure to the air and dipping in a solution of potassium dichromate. SCHÜTZENBERGER and LALANDE give the following proportions:—1 lb. of finely ground indigo is mixed with sufficient water to hold it in suspension, and with from 3 to 8 lbs. of hydrosulphite of sodium, and the same or a sufficient quantity of caustic soda or potash.

Aniline Black.—It has already been stated that in the manufacture of mauve from aniline a large quantity of a black insoluble substance is formed. This aniline black can also be produced by oxidizing an aniline salt with which cotton has previously been impregnated, and thus a very fast colour is produced.

Aniline black was first applied to calico by JOHN LIGHTFOOT of Accrington; according to his original patent a mixture of aniline hydrochloride, potassium chlorate, chloride or sulphate of copper, and sal-ammoniac or an organic acid, is printed on the cloth, which is then aged and passed through a solution of potassium chromate.

This process, however, was soon given up, because the mixture attacked the copper rollers and weakened the cloth. Several other processes were subsequently patented, the first great improvement being effected by M. Cordillot, who replaced the salts of copper by ammonium ferricyanide. This process, however, is expensive, and does not produce such a good black as Lightfoot's method. M. Lauth, therefore, endeavoured to improve the latter, and succeeded completely. Instead of a copper salt he used precipitated copper sulphide, which is printed together with aniline hydrochloride, potassium chlorate, and sal-ammoniac.

The sulphide of copper is obtained by precipitating a solution of copper sulphate with potassium sulphide: 150 grms. of the washed and moist precipitate are mixed with 500 grms. of starch and 250 grms. of water, and this mixture is then added to another mixture, which is composed of—

Tragacanth paste,	½ litre.
Calcined farina,	650 grms.
Water,	950 "
Chlorate of potash,	150 "
Sal-ammoniac,	50 "
Aniline hydrochloride,	400 "

The following two mixtures produce also a good black:—

(1) 14 gals. of water.
26 lbs. of starch.
11 lbs. of British gum.

Boil and add—

9 lbs. of chlorate of potash.
4½ lbs. of sal ammoniac.
6½ lbs. of sulphide of copper.

Allow to cool and then add—

9 lbs. of aniline.
11 lbs. of tartaric acid.

After printing, age for three days at 33° to 35° C., pass through a weak solution of soda crystals, and soap the yarn at 80° C.

(2) 9 galls. of water.
9 lbs. of starch.

Boil and add—

2 lbs. of chlorate of potash.
2½ lbs. of sal-ammoniac.
4 lbs. of sulphide of copper.

Mix and add—

10 lbs. of aniline hydrochloride.

Hang for a day or two and wash.

Aniline greys are produced by a similar process; thus, the following proportions yield a good silver grey:—

Gum water,	1 gal.
Chlorate of potash,	5 ozs.
Sal-ammoniac,	2½ "
Sulphide of copper,	7½ "
Aniline,	5 ozs.
Tartaric acid,	15 "

A darker grey is obtained by using—

Gum water,	1 gal.
Chlorate of potash,	10 ozs.
Sal-ammoniac,	5 "
Tartrate of chromium,	25 "
Aniline,	2½ ozs.
Tartaric acid,	15 "

The tartrate of chromium is produced by dissolving 40 ozs. of bichromate of potash in 1 gal. of water and adding 60 ozs. of tartaric acid.

Lucas' soluble black, which is principally a mixture of copper acetate and aniline hydrochloride, is also used in printing. The liquid black mass is thickened and printed, and the goods are, after being exposed for some days to the air, passed through a dilute solution of soda ash.

John Lightfoot tried also the action of other metallic salts on aniline, and found that among others, the salts of iron, uranium, erbium, and vanadium produce good blacks. At that time (1871), however, vanadium and its compounds were so extremely rare, that nobody could dream of using them for printing. But lately deposits of a vanadium ore have been discovered in Shropshire, from which pure vanadium compounds are prepared on a large scale by the Magnesium Metal Co., near Manchester, who supply it at a price and in sufficient quantities to make it commercially available. The advantage which vanadium has over copper sulphide is, that its compounds are much more stable, and one part will go as far as 200 to 300 parts of the sulphide. Moreover, the process becomes much more simple; it is only necessary to dissolve aniline hydrochloride and chlorate of soda in water, and add to the thickened solution a little vanadic acid in powder.

The quality and peculiar shade of the black depends very much on the kind of aniline which is employed. Pure aniline gives, according to Hartmann, a very brilliant black, while magenta-aniline and pseudotoluidine yield a bluish-black, and the solid toluidine only a dirty brown.

When naphthylamine is used in the place of aniline, a violet is produced. The following proportion has been recommended by a printer:—

Naphthylamine,	8½ oz.
Hydrochloric acid,	5½ oz.
Water,	7 lbs.
Starch,	2 lbs.
Water	4 lbs.
Tragacanth paste containing 3 oz.,	2 lbs.

Boil, mix the two solutions, and when cold, add a solution of 460 grains of chlorate of potash in 2 lbs. of water.

Resist Style.—The object of this style is to produce a white design on a coloured ground. This is effected by first topically printing on the white cloth a substance which is called *resist* or reserve, and possesses the property of preventing the colour from fixing when the cloth is afterwards dyed. Resists may act either mechanically or chemically.

(1) *Fat resists.*—A white pattern on a lilac ground may be obtained by first printing on the cloth a resist consisting of a mixture of suet and gum water, and then padding with weak iron liquor, which of

course does not penetrate the parts which are covered with the resist. The cloth is now aged, dunged, dyed, and cleared. On the white pattern which is thus obtained different steam colours may be printed.

(2) *Resists for Mordants.*—These resists are chiefly employed in madder style, to produce white dots or other patterns on lilac or pink, &c. This is easily effected by printing on the mordants lemon juice or citric or tartaric acids, which combine with the alumina or oxide of iron, and form soluble salts, which are not decomposed by ageing and dunging.

Another resist for iron mordant is stannous chloride, which, as we have seen, is also used for preventing any oxide of iron from being deposited on the alumina mordant, in order to obtain very bright pinks and reds. If therefore stannous chloride is mixed with red liquor, well defined red designs surrounded by purple or lilac are obtained.

(3) *Resists for colouring matters* are almost entirely used for producing white patterns on indigo blue. The substances used for this purpose are principally copper salts, such as the sulphate and acetate, which are thickened and mixed with soap and lard, and printed on those parts of the cloth which have to remain white. After being dried, the cloth is dipped in the indigo vat, which is prepared by mixing together a solution of ferrous sulphate with finely ground indigo and slacked lime. Thus a solution of indigo white is obtained, which is absorbed by the cloth, and on exposing it to the air, takes up oxygen, and thus insoluble indigo blue is deposited in the fibres. By repeating this process, and using vats of different strength, any indigo blue shade may be obtained on the cloth, excepting on those places where the resist has been applied. The indigo white is not in this case absorbed, partly on account of the grease, but chiefly from the chemical action of the copper salt, which by dipping in the vat is changed into copper hydrate, which exerts an oxidizing action on the indigo white; indigo blue being precipitated before the solution can reach the fibre. The colour is therefore only attached to the resist, and is easily removed by washing.

DISCHARGE STYLE.—This style resembles the resist style, in so far as its object is to produce white patterns on a coloured ground, but differs from it by the *discharge* being only applied after the cloth has been dyed. The materials used as discharges are chiefly oxidizing agents, such as chlorine, chromic acid, &c.

Thus, to obtain a white pattern on an indigo-blue ground the dyed cloth is padded with a weak solution of potassium dichromate, and carefully dried in the cold and dark. It is next printed with tartaric or oxalic acid. Free chromic acid is thus formed, which at once oxidizes and destroys the blue. By mixing the discharge with a lead salt, lead chromate is formed, and a yellow pattern on a blue ground is thus produced.

A mixture of potassium ferricyanide and caustic soda also discharges indigo completely.

Potassium dichromate cannot be used as a discharge for other colours, because it injures them by its oxidizing action. To discharge madder colours, a solution of tartaric acid or arsenic acid is thickened with gum and pipe-clay and printed. After the cloth has been suspended for a day or two, it is passed through a weak solution of bleaching powder, and then well washed. Bleaching powder acts on madder colours and other fast colours very slowly; but on the parts of the cloth where the acid has been applied free chlorine is liberated, and acts instantaneously on the colour.

Prussian blue and mineral colouring matters may also be discharged by chemical reactions, as we shall see under the next heading.

CHEMICAL PRINTING.—The chemical principles which are involved in this style are so very simple, that it will be only necessary to illustrate them by the following examples:—

Prussian Blue.—To dye the whole surface of a piece of cloth with this colour it is padded in a solution of acetate or sulphate of iron, or a mixture of both, and then, after being dried, winced in chalk and water. It is next winced in a solution of potassium ferrocyanide, which is slightly acidulated with sulphuric acid. If a blue design is required the cloth is printed with a thickened iron solution (acetate or sulphate), aged, winced in chalk and water, and dyed in an acidulated solution of potassium ferrocyanide.

The formation of Prussian blue is easily explained. By the processes of ageing and wincing in chalk and water, ferric oxide is deposited in the fibre, and this, by the action of the acid and the ferrocyanide, is then converted into Prussian blue.

If a white figure is required on a ground of Prussian blue it is printed with a paste containing caustic potash, and then passed through a solution of oxalic acid. The alkali converts the Prussian blue into soluble ferrocyanide and oxide of iron, which is dissolved by the oxalic acid.

Chrome Yellow and Orange.—A piece of cloth is dyed with chrome yellow by first padding it with a solution of lead acetate, and after drying passing first through a weak solution of sodium carbonate and then through a solution of potassium dichromate.

To print this colour a thickened solution of lead acetate or nitrate is first printed on the cloth, which after drying is treated as above.

Chrome Orange is obtained by boiling the cloth in lime water, after it has been dyed or printed with chrome yellow. A chrome yellow pattern on orange ground is produced by printing an acid on the orange, while greens are obtained by first applying a mixture of iron liquor and lead acetate, and then wincing in an acidulated solution of yellow prussiate and bichromate of potassium.

Another style of green is produced by printing a mixture of lead nitrate and indigo precipitate (the compound of stannous oxide and indigo white), fixing by passing through a solution of sodium carbonate, and dyeing in potassium dichromate.

Bistre, Manganese Brown or Bronze.—To obtain this colour the cloth is padded with a solution of manganese chloride, and after drying passed through a strong cold solution of caustic soda to precipitate manganous hydrate, which is oxidized to the brown oxide, either by exposing the goods to the air, or by dipping them into a solution of bleaching powder.

A white design on brown ground is produced by printing on bistre a solution of stannous chloride, by which the brown oxide is reduced to manganous chloride, which is readily removed by washing. The brown is also discharged by most acids, and therefore by using certain acid mordants the oxide of manganese is removed, while the mordant becomes fixed, and may then be dyed in the usual way. In this way a great variety of coloured designs on a brown ground can be produced.

Iron buff consists of ferric hydrate, and is obtained by padding or printing either with ferric nitrate or a mixture of ferrous acetate and sulphate *(buff liquor)*, ageing, and passing through milk of lime or caustic soda. When after ageing a mixture of oxalic and tartaric acids is printed on the cloth, the iron is discharged, and thus white patterns on a buff ground are formed.

COLOURS FIXED BY ALBUMIN.—The fixing of pigment colours by albumin is a merely mechanical process. Commercial albumin is obtained from blood by removing the coagulum, and evaporating the clear serum at a moderate temperature. Egg albumin is also sometimes used, and consists of the dried white of eggs.

Good albumin is perfectly soluble in water at the common temperature, but becomes insoluble or coagulates above 70° C. Therefore on mixing its solution with a pigment colour and starch paste or tragacanth, printing the mixture on cloth and steaming it, the albumin coagulates and incloses the pigment in the fibre so firmly that the colour becomes permanently fixed. The principal pigment colours which are fixed in this way are ultramarine, GUIGNET's green, emerald green, chrome yellow, orange and red, iron ochres, &c.

Albumin is also used for printing aniline colours, but then it acts not only mechanically but also chemically, because all substantive colours have the same affinity for albumin as for wool and silk. Such colours are therefore permanently fixed by mixing them with a solution of albumin and gum, printing the mixture in the usual way, and steaming the goods. In the place of albumin glue may be used, which is boiled with 20 parts of water, and to this solution so much potassium dichromate is added that the liquid becomes straw yellow. In this solution the colour is dissolved; and after thickening with starch or gum it is ready for printing. Goods thus treated do not require steaming, the colour being fixed by exposing the goods to sunshine.

To print with aurin and peonin the colour is mixed with magnesia or oxide of zinc and a solution of albumin. In this case the colour forms with the oxides insoluble lakes, and may therefore be also fixed by using a mixture of gum water and glycerin in the place of albumin.

THE DYEING OF COTTON.—In the dyeing of cotton, as well as in that of other fabrics, great care must be taken to avoid an uneven or patchy coloration. To do this, two conditions must be carefully fulfilled; (1) The goods must never be dipped into the dye beck in the dry state, but must be completely moistened with water. (2) They must be always moved about in the bath, in order to avoid a partial exhaustion of a portion of it.

If in the following recipes weights or measures are given, they are intended for 10 lbs. of yarn or cloth.

(1) *Colours not requiring a Mordant.*—The number of substantive colours which can be fixed on cotton without the intervention of a mordant is but small.

Safflower was, before the discovery of the aniline colours, used for dyeing on cotton delicate rose and pink tints. For this purpose an alkaline solution of crude carthamic acid is slightly acidulated with citric acid, and the cotton steeped in it until it has acquired the desired shade.

Annotta is fixed on cotton by dissolving it in a hot solution of soda crystals, steeping the goods in the liquid for twenty minutes or longer, pressing them, and washing in slightly acidulated water. Better results are, however, obtained by first impregnating the cotton with tannate of tin. It may also be fixed by the same method which is used for steam printing.

(2) *Dyeing on Mordants.*—Most substantive colours and, of course, all adjective colours can be fixed on cotton only by the intervention of a mordant, with which the yarn must first be impregnated before it is passed into the dye beck. Some substantive colours will, however, dye on non-mordanted cotton very pales shades, so-called tint shades.

Aniline Colours.—Aniline red, as well as its coloured derivatives, are readily fixed on cotton by first saturating it with tannin. For fine work a solution of tannic acid is used, while for common work a decoction of sumach or of other astringent substances is employed. After the cotton has been thoroughly saturated, it is wrung out, and now passed through a warm solution of tartar emetic. According to the shade required, these processes are repeated once or more. The dyeing may be performed in a cold or warm solution of the colour.

Another good mordant for cotton is oxide of tin, which is fixed by passing the goods through a solution of stannate of soda, and dipping them in very dilute sulphuric acid.

Starch has also a peculiar attraction for aniline colours, and may therefore be employed as a mordant. REIMANN recommends to mix ¼ to ½ oz. of starch with 4 oz. of water, and to add this mixture to so much boiling water, that 1 lb. of cotton can be easily worked in it. The colour becomes faster and brighter if a hot solution of 60 grains of isinglass or gelatin be added.

Spirit blue is fixed on cotton by working it for twelve hours in a bath containing for each 5 lbs. of cotton 1 lb. of Castille soap, and dyeing in a bath to which some acetate of alumina has been added.

For dyeing with *iodine green*, the cotton is steeped over night in a cold solution of sumach, then passed through red liquor, and dyed in a cold aqueous solution of the colour.

Saffranin.—The cotton is well washed with soap, and worked for two hours in a cold solution of acetate of alumina of 5° to 6° Tw., wrung out and worked in a strong soap bath of 60° C. After being washed, it is dyed in a solution of the colour at about 50° to 60° C. Thus yellowish pinks and cherry red may be produced.

Phenylene Brown or Bismarck colour is dyed on cotton by preparing the yarn with sumach and acetate of alumina, and working it in a cold or tepid dye bath. The addition of a little bichromate of potash produces darker and more reddish shades.

Eosin produces very delicate rose and pink shades. The cotton is first well worked in a hot bath containing 1 lb. of Castille soap for 10 lbs. of cotton, and is then steeped in a solution of 4 lbs. of sugar of lead. After these processes have been repeated two or three times, the cotton is worked in an aqueous solution of the colour, which goes on slowly but very uniformly.

Quercitron, Flavin, and Fustic are fixed by working the cotton, first in sumach, and then in a solution of tin crystals. For dyeing, either a solution of flavin, or a solution of the extract of the dyestuff, or a decoction of the latter, may be used.

A very good yellow is obtained by steeping the cotton in a decoction of 1 lb. of sumach, wringing out and working it for half an hour in acetate of alumina at 1° to 2° Tw. It is then again wrung out and dyed in a hot decoction of 5 lbs. of quercitron, to which 2 ozs. of tin crystals are added.

Turkey Red.—This beautiful colour, which is distinguished by its great brilliancy and stability, is produced by a very singular process. It is a madder colour, differing from all other colours produced by this root by being not only much brighter, but also by being less readily attacked by acids and by bleaching powder.

The methods which are used for producing this remarkable colour are more or less complicated, the first process, however, in all cases, being to saturate the cloth well with a vegetable oil. Generally *Gallipoli oil* is used; this is a common olive oil, containing extractive matters, and possessing the property of forming readily with a weak solution of pearl-ash or caustic soda a perfect emulsion, *i.e.*, a milky liquid, in which, by the naked eye, no oily drops can be seen. With this emulsion the goods are thoroughly saturated, and then exposed to the air for twenty-four hours in a room, which formerly was only heated in winter. The oiled cloth absorbs oxygen so rapidly that it becomes hot, and even sometimes takes fire. The higher the temperature gets during this oxidation, the more brilliant will be the colour; and therefore dyers prefer now to hang the oiled goods in a room having a temperature of 60° to 65° C., of course great care being taken to avoid combustion taking place. The same operation is repeated, according to the required shade, several times. It appears to be of advantage to add to the last bath some sheep's dung. The excess of oil, or rather that portion which has not been changed by oxidation or the action of the alkali, is now removed by washing.

The next process is *galling* and *aluming*, which is sometimes done by separate treatments. The cotton is passed through a bath containing sumach or nutgalls and aluminium acetate, then dried and aged, and now passed through chalk and water, in order to fix the alumina completely. The dyeing, which follows next, is done in a bath containing ground madder, garancin, or artificial alizarin. The cotton acquires now a heavy brown colour, which changes into a brilliant red by two or three soapings, or by a passage through an acid. Some dyers add to these baths pearl-ash or tin crystals.

Since the introduction of artificial alizarin the dyers prefer to treat the goods before soaping with caustic soda, to dissolve any excess of alizarin, which thus can be easily recovered, a process which would be more difficult in the presence of soap.

Turkey red consists chiefly of a peculiar compound of alizarin and fatty acids, which is soluble in ether and petroleum naphtha. On evaporating these solutions a splendid scarlet fatty mass is left behind, consisting of alizarin and fatty acids, which may be separated by dissolving in hot spirits of wine, and precipitating the fatty acids by the addition of a little water. The yarn or cloth, after being exhausted with the naphtha, loses all its brilliancy, and retains only a dull shade, resembling that which madder dyes on tin mordant.

The single threads of cotton dyed with turkey red contain the colour only on the surface, the oil preventing the alizarin from penetrating the fibre. This is undoubtedly the cause of the great brilliancy of this colour, because all colours appear much brighter when they are fixed on a white ground; while, if the whole colour is absorbed by the fibre, it appears dull. The presence of a fat is also undoubtedly the cause of the greater stability of turkey red, when compared with other madder reds. As the colour exists only at the surface, the quantity of alizarin required is but small, a piece of 60 yards taking up only about 5 to 6 ozs. of alizarin paste of 10 per cent., while to obtain a similar shade on cloth not oiled 2 lbs. would be necessary.

The quantity of alumina fixed in dyeing turkey red is always very small; some have even doubted that it plays a part in the process, while others believe that its presence is essential, the variations in shade being dependent on the quantity of the alumina, and not of that of the oil.

The following facts will show why this point is not easy to settle.

An imitation of turkey red is now obtained by impregnating the cloth with red liquor, drying, and passing it through a soap solution, in order to obtain a compound of alumina with fatty acids. The cloth thus prepared assumes on dyeing with madder or alizarin a very bright red. In this process a piece of 60 yards requires only about $\frac{3}{4}$ gals. of red liquor at 7 Tw., containing 200 grains of alumina; but of this quantity only a fraction is fixed. This is shown by the fact that when alizarin is fixed by steaming, the same shade requires only about $\frac{1}{6}$ of that quantity of alumina, and this is also only partially fixed, most probably not more than one-half of it remaining in combination with the alizarin. From these numbers, and the quantity of alizarin which is fixed in dyeing, we come to the conclusion that a piece 1 yard long and $2\frac{3}{4}$ feet wide contains about $\frac{1}{600}$ grain of alumina and $\frac{1}{200}$ of pure alizarin, while the ash of the piece weighs about $\frac{1}{6}$ of a grain.

A very good imitation of turkey red is also produced by dyeing goods, mordanted with a strong solution of acetate of alumina, with anthrapurpurin.

Brazil wood, and the other red woods, are used for dyeing common reds. The goods are mordanted by steeping them in hot sumach liquor, and then passing them through red spirits (stannic chloride). After washing, they are dyed in a bath containing brazil wood and some fustic or quercitron. The latter are added in order that the yellow which they impart may brighten the crimson, produced by the red woods, into a scarlet.

Inferior reds are obtained by simply saturating cotton with a solution of Brazil wood extract in tin spirits and passing through water; or they may be obtained by first fixing an alumina mordant and then dyeing.

Examples.—*Common Red*:—Steep in a hot decoction of sumach and allow to cool, wring, and pass in tin spirits at 2° Tw. Wash, and pass for half an hour in a hot decoction of 3 lbs. of Lima wood and 1 lb. of fustic.

Crimson.—3 lbs. of sumach.
Tin spirits, at 20° Tw.
3 lbs. Brazil wood.
1 lb. logwood.

Proceed as above.

Logwood is chiefly used for dyeing cheap blacks; it yields with alumina alone a purplish black, and with iron mordant a dull brownish black. A mixture of the two is therefore generally used, and to the dye bath quercitron and other dye woods are often added to modify the shade.

Faster blacks are obtained by using with the logwood some astringent matter. The goods are first steeped into a decoction of sumach or nut galls, then passed successively through lime water, solution of copper sulphate, boiling logwood liquor, and lastly through a solution of green vitriol.

A fine black may also be obtained by first fixing an iron mordant, and then steeping in a bath containing sumach and logwood.

The old fast black was obtained by first dyeing with indigo, then passing the goods through a decoction of nut galls or sumach, and finally through a solution of green vitriol.

Colours Fixed by Oxidaton.—The colours of this group are the same as those employed in printing. It is, therefore, not necessary to repeat what already has been said about the formation of these colours; it is sufficient to describe simply the process.

Catechu is much used for dyeing brown or fawn; the goods are worked in catechu liquor containing a copper salt, and then in a weak solution of potassium dichromate. Other shades are obtained by steeping the goods, which have been worked in the catechu bath, in weak caustic soda or milk of lime, and then exposing them to the air.

Aniline black can be dyed by different methods.

According to Persoz, a good black is obtained by steeping cotton in a solution containing 8 per cent. of potassium dichromate, and then working it in a solution consisting of 10 parts of aniline, 10 of sulphuric acid, 25 of strong hydrochloric acid, and 200 of water. The yarn is dried on hot plates and steamed.

Müller-Pack uses ferrous chloride, which he prepares by dissolving 3 parts of iron in a mixture of 10 parts of hydrochloric acid and 10 of water; this solution is diluted with so much water that it stands at 70° Tw. The yarn is steeped in this liquor for two hours, and then exposed to the air for twelve hours. On the other hand, a solution is prepared by dissolving 3 parts of aniline and 5 parts of hydrochloric acid in water, and adding to this liquid a solution of $2\frac{1}{10}$ parts of potassium chlorate in 30 parts of water.

The yarn is steeped in this mixture and then heated gradually from 30° to 50° C. in a closed vessel; then after being exposed to the air for some time, it is passed through a solution of potassium dichromate. The black thus produced assumes a bluish shade by passing the goods through dilute sulphuric acid and washing them with water and dilute caustic soda. Lucas' soluble aniline black, which has been described under printing, is also used for dyeing. Another soluble black is prepared by Coupier; he heats a mixture of 175 parts of commercial aniline with an equal quantity of nitrobenzol, 200 parts of hydrochloric acid, 16 parts of iron filings, and 2 parts of finely divided copper, for eight hours gradually to 200°. The black mass thus obtained is soluble in dilute acids, and is readily fixed upon the cotton after passing through this solution, by dipping it in an alkaline bath.

Another method for producing an aniline black has been proposed by Lauth. He dyes the cotton first with manganese brown, by working it for an hour in a bath of manganese chloride at 70° Tw., and then steeping without washing in boiling caustic soda at 17°, in which some lime is suspended. After washing it is passed through a tepid solution of bleaching powder. The yarn thus charged with bistre is again washed and steeped in a cold acid solution of aniline for one or two minutes. According to the shade which is wanted, the aniline solution is composed of 10 to 20 parts of aniline, 60 of sulphuric acid, and water to make up 1000 parts. After dyeing, the cotton is washed and passed through a boiling solution of soap or soda crystals.

Indigo.—Among the colours fixed by oxidation indigo is the most important. The process which is used for dyeing cotton with indigo has already been shortly explained (see *Resist Style*).

Finely ground indigo is very thoroughly mixed with hot milk of lime and placed in a vat, into which a hot solution of ferrous sulphate is afterwards gradually introduced. By the reaction thus set up indigo white is formed in the presence of an excess of lime, and quickly dissolves. The proportions which are generally used are—

Indigo	1
Crystallized ferrous sulphate	3
Slacked lime	3

But some dyers prefer an excess of lime, although the proportions as given above contain already more lime and sulphate than required by the theory. This, however, is necessary; for the surface of the liquid being exposed to the air, a scum of regenerated indigo is always floating on the surface; which on gradually sinking down, redissolves again.

The lime cannot be replaced by other alkalies, because vats prepared with caustic soda oxidize much more rapidly than lime vats; the reason being that the insoluble lime protects the ferrous hydrate and prevents its rapid oxidation. Moreover, the compound of lime and indigo white is much more easily absorbed by cotton than the soda compound. After mixing the components, the liquid is left to stand for some hours.

The cotton is now immersed in the vat until saturated with the liquid, and then the colour developed by exposing the goods to the air.

By varying the strength of the vat as well as the number of immersions, different shades, ranging from pale blue to bluish-black, can be obtained.

In order to obtain uniform and stable shades it is best to commence with a weak vat, and then use gradually stronger ones. The indigo is thus made to penetrate the fibre more completely.

Mineral colours are also much employed for the dyeing of cotton. It is not necessary to explain here the methods which are used, because they are exactly the same as those employed in chemical printing; the principle being to deposit, by means of a double chemical decomposition, a coloured precipitate in the fibre.

It can further be easily understood, that by uniting several of the colours which have been described on the same fibre, any desired shade can be produced. The following examples may serve for illustrating this point:—

Green colours are produced by first dyeing a light indigo blue in the vat, and after fixing an alumina mordant, dyeing in quercitron or fustic liquor. Or the blue goods may be changed into green by using a lead mordant, and then raising the colour in potassium dichromate.

Good greens are also obtained by dyeing with quercitron or fustic on Prussian blue.

Grey colours are in most cases nothing but dilute blacks, and therefore the same materials which are employed for producing black are used, only in smaller quantity. The tints are modified into yellowish, bluish, reddish grey, &c., by the addition of quercitron, fustic, Brazil wood, logwood, catechu, &c.

Brown colours are generally obtained by a mixture of yellow, red, and blue. Thus, quercitron may be dyed on a tin mordant, fixed by sumach, and the colour be raised by means of Brazil wood and log wood. Or the cotton is first dyed with annotta, then worked in a decoction of sumach and fustic, passed through an iron mordant, and the colour raised in a decoction of logwood and Brazil wood.

The Dyeing of Wool and Silk.—All substantive colours dye wool and silk without the intervention of a mordant; but in several cases mordants are used, because it has been found that the colours thus obtained are brighter and faster.

Adjective colours always require a mordant, which may be applied in two different ways:—

(1) The mordant is first fixed on the wool or silk, which are then worked in a solution of the dye stuff.

(2) The wool or silk is dyed in a bath containing the colouring matter and mordant in solution together. The chemical process taking place in this case may be illustrated by the following example, which also serves to show the different affinity of wool and cotton for colouring matters:—

Dissolve a few grains of flavin in boiling water, and add some drops of a solution of stannous chloride (tin spirits). A yellow precipitate will be formed, consisting of a compound of flavin and tin oxide. Add now a little oxalic acid or tartaric acid: the precipitate will completely dissolve, and a colourless solution will be obtained. Immerse then in the boiling solution some wool and some cotton; the wool will very soon assume a bright yellow shade, while the cotton will remain perfectly white.

We thus see that organic acids have the property of dissolving the compound of flavin and stannous oxide; but wool has the power to take it up from such a solution, and of combining permanently with it, while cotton does not possess this property.

The mordants used in the dyeing of wool and silk are the same as those employed in the printing and dyeing of calico. But there is one specific mordant for wool which must be mentioned here. This is potassium dichromate (bichromate of potash), which has the property of combining with wool, which takes it up from an acid solution, probably partially, in the form of chromic oxide. Potassium dichromate is used chiefly as a mordant for browns, olives, greys, and blacks; and produces very full colours, evidently on account of its oxidizing properties.

Preparation of Wool for Dyeing.—The first process to which spun wool is subjected is to remove all the oil with which the wool becomes saturated in spinning. This is effected by washing it in a warm bath (not exceeding 50° C.) containing a solution of soap and ammonia, or soda crystals, or soap only. After being well washed, the wool is thoroughly washed in running water, and is then ready for dyeing.

Preparation of Silk for Dyeing.—Raw silk is prepared for dyeing by *scouring* it, or passing it through a hot soap solution, which removes the gummy matters. After washing, it is bleached by gaseous sulphurous acid, then passed through a hot solution of tartar, and finally well washed with warm water.

Silk has not the same attraction for colours as wool has. Some of them go much more readily on the former, others more easily on the latter; the methods used for dyeing these fibres are therefore not always the same, but in most cases similar enough to allow us to consider them together. Many methods employed for dyeing wool cannot be used for silk at all, because it does not stand such rough treatment as wool, being a much more delicate material.

Aniline Colours.—The salts of rosaniline, as well as those of the different methyl and ethyl violets (Hofmann's & Paris violets) are mostly soluble in water, and the dyeing of them on wool is a very easy operation; the yarn is simply suspended in a hot and not too concentrated solution of the colour, until it has assumed the required shade.

It is very important that the colour should be completely in solution, as undissolved particles would attach themselves to the fabric and produce spots. A very good plan is to mix the colour with glycerin by grinding, boiling the mixture with water, and filtering through woollen cloth. Another simple method which some dyers use is the following:—A woollen filter is placed in one corner of the dye beck, so that its bottom dips some inches under the liquid. In the filter the required quantity of colouring matter is placed, tied up in a bag of flannel; the colour then dissolves only slowly, and being filtered through two layers of wool, the solution is free from any undissolved particles and impurities.

In dyeing wool the solution is usually hotter than that used for silk. To produce even shades the solution of the colour is only gradually added, and before each addition the fabric must be taken out, and only put back after the bath has been well stirred up.

The phenyl violets and blues (spirit blue) are almost insoluble in water, but readily soluble in alcohol and wood spirit. To dye with them an alcoholic solution, generally mixed with glycerin, is added gradually to hot water, in which the wool is suspended. The addition of glycerin has been found of advantage, because it increases the solubility of the colour, which, moreover, by the evaporation of the alcohol would be precipitated on the wool too rapidly and unequally. By adding to the bath stannic chloride and tartar or bisulphate of soda, the brightness of this colour is much increased.

Silk is best dyed in a soap bath, and the colour brightened by a passage through dilute sulphuric acid.

Alkali Blues are best fixed on silk and wool by adding to a hot solution of the colour a little borax or soda crystals. The wool takes up the salts in an almost colourless state, but fixes them completely; when it has taken up sufficient, which is easily seen by dipping a little of it in acidulated water, the whole is washed with water, and the colour raised in a bath of very dilute sulphuric acid.

The soluble blues may also be dyed on wool by the following process:—

10 lbs. of wool are boiled for half an hour or more in a bath containing ¾ lbs. of tartar, ½ lb. of aluminium sulphate, 5 oz. of solid stannic chloride, and ½ to 1 lb. of sulphuric acid at 150° Tw., and then dyed in a boiling solution of the blue, to which some sulphuric acid has been added.

Iodine Green.—Wool is dyed by two methods:—

1. It is prepared in a bath containing 3 lbs. of hyposulphite of soda and 1½ lb. of hydrochloric acid; and being heated to 50° C., the temperature is gradually raised to 70° C., and then the wool is washed with cold water.

To the dye-bath some acetic acid is added, and the dyeing commenced at 50° C., and the temperature gradually raised to 70° C.

2. Two baths are prepared, one containing the colour and some ammonia, in which the wool is slowly boiled until it assumes a greyish-green shade, which is brightened in the second bath containing acetic acid, and heated to 40° C.

Silk will dye in a warm aqueous solution, to which some picric acid is added if a yellowish shade be required. It may also be dyed in a soap bath, and the colour brightened in a bath containing acetic acid, and if necessary, some picric acid.

Saffranin, which produces a beautiful pink and rose, is simply dyed in a dilute aqueous solution, both on wool and silk.

Magdala red produces a similar shade, but the colour exhibits a beautiful fluorescence.

Manchester brown is dissolved in hot water, to which for one part of the colour half a part of sulphuric acid is added.

Picric acid fixes very easily on wool and on silk in an aqueous solution. To obtain brighter and faster shades wool is previously mordanted with alum and cream of tartar, while a fast yellow on silk will be obtained by passing it after dyeing through a warm solution of sugar of lead, and brightening the colour in a weak soap solution.

Naphthalene yellow dyes a very pure yellow, not showing the greenish tinge which is imparted by picric acid. It is therefore also much employed for dyeing orange or scarlet on silk and wool. To a boiling dilute solution of the colour the required quantity of pure magenta is added, the proportions varying according to shade—a good scarlet being obtained by using 30 parts of the yellow to 1 part of magenta.

Eosin dyes on wool and silk, pink, rose showing a beautiful scarlet reflection, and very bright but yellowish scarlets. It is fixed on wool by dyeing in a boiling aqueous solution, containing a little acetic acid, and raising the colour in a boiling solution, containing for 100 parts of wool 2 parts of oxalic acid, and 2 parts of acetate of alumina.

Silk is first softened in boiling water and dyed in a soap solution, which, for the lighter shades, is acidulated with acetic acid, and for deeper ones with sulphuric acid.

Aurin or *yellow corallin* produces on wool a bright and fast orange. It is almost insoluble in water, but dissolves readily in dilute alkalies; but is not taken up by wool from such a solution. Therefore, to dye with it, acetic (or some other acid) is carefully added to a boiling alkaline solution of the colour, until the liquid begins to become turbid. The alkali is now completely neutralized, and the colour quickly absorbed by the wool. Another good method is to add first an alcoholic solution of aurin to boiling soap-water, and then an acid, until the liquid becomes turbid. This bath is also used for silk.

Peonine or *Red aurin* is dyed in the same way, and produces a fine scarlet.

Purree yields different yellow and orange shades, and may be used for silk and wool. To obtain the darker shades the colouring matter is dissolved in the smallest quantity of nitric acid, and the solution diluted with water. Yellow shades are obtained by dissolving purree in a solution of borax and sal-ammoniac.

Annotta is also much used for dyeing orange tints, chiefly on silk, which is simply worked in a warm solution of the dyestuff and soda crystals, to which sometimes some soap is added. After washing in warm water, the colour may be brightened by passing the silk through a dilute solution of tartaric acid.

Safflower is fixed on wool and silk in the same way as on cotton. The only precaution which has to be taken is to employ a safflower precipitate which is completely freed from the yellow colouring matter, or else the latter would also fix on the animal fibre, and spoil the pure rose-tint.

Archil and *French purple* were, before the discovery of the aniline colours, much used for dyeing different shades of purple, violet, lilac, lavender, &c. By employing an acid at the same time the redder shades are obtained, while, in presence of an alkali, the shades become bluer.

Indigo.—This is one of the most important colours for woollen goods, being very fast and stable, and not affected by alkalies nor by most acids. There are two methods for fixing indigo on wool:—

(1) *Indigo Vat, or Hot Vat.*—This style of dyeing is very similar to the dyeing of cotton by indigo, the wool being immersed first in an alkaline solution of indigo white, and then exposing it to the air. But the preparation of the vat is quite different; none or only little lime being used, nor any ferrous sulphate, the constituents of the vat being the carbonates of potassium or sodium, or the caustic alkalies, and some organic matter, which readily undergoes a peculiar kind of fermentation, by which hydrogen is evolved. This combines with the indigo blue and forms indigo white, which dissolves in the alkali. The different kinds of vats which are used are the following, which are all worked hot:—

(*a*) *Woad and Pastel Vat.*—Formerly the only indigo-yielding constituent of this kind of vat was woad, but now finely-ground indigo is always added. The colouring matter of woad undoubtedly adds to the effect, but its principal use is in furnishing the fermentable matters. Pastel is a kind of woad growing in France; it is richer in indigo blue than common woad, but is also now only used in combination with indigo. To prepare a woad vat, water is heated to the boiling point, and 50 parts of woad, 3 of madder, 3 of bran, and 9 of pearl-ash are introduced, and then 3 parts of indigo. The mixture assumes, after standing for eight to ten hours, a greenish-yellow colour, and changes into a brown by the addition of 4 to 5 parts of slacked lime.

(*b*) *Indian or Potash vat* is prepared by using equal parts of indigo, bran, and madder, and three times as much pearl-ash, and heating the mixture with water to 50° C. The addition of madder to these vats is believed to produce darker colours, having a violet tint. This, however, appears to be merely fancy, because it is very improbable that under these conditions the colouring matter of madder could be fixed on the wool. The utility of madder is undoubtedly due to the sugar and other fermentable bodies which it contains.

(*c*) *German Vat.*—This is prepared by heating water to 50° to 60° C., and adding first soda crystals, bran and indigo, and then, when the fermentation has well set in, some lime. To quicken the fermentation molasses is often added, and lately it has been proposed to substitute the bran by ground turnips or other similar roots, or fleshy fruit.

The dyeing in these vats is very simple: the goods after being well wetted are suspended in the liquor for one or two hours, and well agitated all the time to insure a uniform colour. On taking them out they rapidly colour blue, and if the required shade has not been obtained the goods are again repeatedly immersed. They are then washed, first in dilute acid, and next with running water.

The colours dyed by the vat are very fast, but dull, and are chiefly applied to knitting wool and the cloth used in the army and navy.

(2) *Dyeing with Indigo-sulphuric Acid.*—The blue thus obtained is brighter, but less stable, than the vat blue. It has now been almost completely superseded by aniline blue. Formerly each dyer prepared his own indigo solution by dissolving 1 part of indigo in 4 to 5 parts of Nordhausen acid, and dyeing from this solution after diluting it with water. The shades thus obtained are not pure and bright, because indigo contains also reddish and brown colouring matters, which readily fix on wool. To avoid that, wool is boiled with the solution of indigo-sulphuric acid until it is saturated and assumes a deep bluish-black colour. It is now washed and boiled with a weak solution of soda crystals (3 parts to 1000 parts of indigo). The pure blue colour now dissolves again, while the wool retains the dirty reddish and brown colours. The blue solution thus obtained dyes, after being acidulated, much purer shades than a solution of indigo in sulphuric acid.

These two preparations of indigo are now replaced by indigo carmine (the sodium salt of indigo-sulphuric acid). The wool is first boiled in a solution of alum and tartar, and then dyed with an acidulated solution of the carmine. The blue thus produced is chiefly used for producing a brilliant green with picric acid, which is simply added to the dye-bath as soon as the wool has taken up a quantity of the blue. Silk is dyed with indigo in the same way.

To obtain a bright green the dyeing must not be done in tin, but in copper. To dye 10 lbs. of wool with picric green, the water is first boiled with 1 or 2 lbs. of aluminium sulphate; then 1 lb. of crystallized alum and 1 lb. tartar is added. It is now dyed with indigo carmine, and as soon as the blue has gone on the wool, a sufficient quantity of picric acid is added to the bath. A good imitation of French purple is obtained in the following way:—

50 lbs. of yarn are boiled in a tinned vessel with 8 lbs. of alum, 2½ of tartar, and 5 of tin solution. The wool is removed, some cold water is added, and a sufficient quantity of indigo carmine; the wool is dyed in this solution at a boiling heat, and left over night. It is now washed and dyed at 75° C. in a bath containing 10 lbs. of violet mordant, and a sufficient quantity of magenta crystals.

The tin solution is prepared by dissolving 12 lbs. of granulated tin in a mixture of 60 hydrochloric acid and 9 nitric acid.

The violet mordant is obtained by dissolving 16 lbs. of potassium dichromate, and adding a mixture of 32 lbs. of sulphuric acid at 130° Tw., and 32 lbs. of water, and then very gradually 12 lbs. of methylated or wood spirits. The solution thus obtained contains chrome alum; and it appears therefore much more rational to use this salt, which is now prepared, or rather obtained as a bye-product, in the manufacture of artificial alizarin.

Red Indigo Carmine, *Indigo Purple*, is the sodium salt of indigo-purpuric acid (see Indigo). It dyes a deep violet, and is chiefly used for modifying the shades produced by archil and French purple.

Cochineal is a most important material for dyeing wool, producing a splendid bright, pure, and fast scarlet. It is also employed for dyeing orange, pink, rose, purple, &c.

Scarlet is obtained by boiling the wool with ground cochineal, stannouscchloride, and cream of tartar or oxalic acid.

To produce a bright scarlet, the water must be first purified. This is done by heating it to 75° to 90° C., and then adding ½ to 1 lb. of perchloride of tin. Soon a yellowish-grey thick scum appears at the surface, which is removed; the water must all the time be kept near the boiling point, but must not boil. After it is perfectly clear, for each 10 lbs. of wool, 1 lb. cream of tartar, 1¼ lbs. solid chloride of tin, and 1 to 2 lbs. ground cochineal are added, and the wool left in the hot solution for half to three-quarters of an hour.

In the place of cream of tartar oxalic acid may be used; but in this case the water must not contain lime salts, or if so, they must be carefully removed, or else oxalate of lime is precipitated on the wool, and the colour becomes dull.

Lac Dye is employed in a similar way: for 10 lbs. of wool are required, according to shade, 1 to 2 lbs. of cochineal; 1 lb. of chloride of tin solution; ½ lb. of tartar; and 3 to 6 lbs. of a mixture of equal parts of lac dye and hydrochloric acid, which is kept ready for use.

This scarlet is not so bright as cochineal scarlet, and has a yellow tinge, but is much used because it it is a very fast colour, which is not much altered by fulling.

The tin solution is prepared by dissolving 5 parts of solid perchloride of tin, and 1 part of tin crystals in so much water that it stands at 34° Tw.

Yellowish scarlets are obtained by adding to the dye beck a decoction of fustic, while by the addition of red woods, archil or logwood, darker or brownish shades are produced.

Cochineal Rose and Pink are dyed with ammoniacal cochineal; the mordants being alum, stannous chloride, and cream of tartar.

In order to obtain bright cochineal pinks, the yarn is first treated with a cold solution of 1 lb. of soda crystals in 10 lbs. of water, and then very well washed. It is mordanted in a tinned boiler in a solution of—

1 lb. of alum.
½ lb. of tartar.
1 lb. of tin solution.

and dyed in a hot, but not boiling solution of ammoniacal cochineal, to which some tin solution has been added.

To obtain a scarlet on silk, it is first dyed orange with annotta, and then dyed with ammoniacal cochineal.

In dyeing with cochineal, as well as with other colours, a most important point is to stir the dye-bath well up after the dyestuff has been introduced. If the dyed wool appears spotted or streaky, it is in ninety cases out of a hundred the fault of the dyer, who has not paid the required attention to this point, and was in too great a hurry to commence dyeing before the dye bath had been thoroughly mixed.

Brazil wood and the other red woods are used for obtaining a bright but not a fast scarlet. For this purpose the wool is first mordanted in a boiling solution of alum (which must be free from iron), cream of tartar, stannic chloride, and copper sulphate, for one or two hours. After washing, the yarn is left lying for two or three days, and then dyed in a boiling decoction of Brazil wood, to which, according to shade, some logwood may be added.

The following recipe yields a very bright red:—

Fill a copper boiler with water, and add to the boiling liquid—

4½ lbs. of pure alum.
6 oz. of tartar.
1¼ oz. of blue vitriol.
6 oz. of tin solution.

Boil for eight minutes, add a little cold water, and boil the yarn for one and a half hours, and allow it to remain in the liquid for two or three days. Wash and dye for two hours in a boiling decoction of Lima wood.

In the place of tartar cheaper substances are often used, principally acid sodium sulphate (bisulphate of soda).

A faster colour produced by Brazil wood is *chrome brown*, which is obtained by first mordanting the wool in a boiling solution of potassium dichromate and tartar or sulphuric acid, and after leaving it hanging in the air for some hours, washing it quickly with a little water. The yarn is then dyed in a boiling solution of Brazil wood, to which, according to the shade required, either fustic or logwood is added.

Cheap reds on silk are obtained by passing the goods first through a solution of extract of Brazil wood, then airing them and passing them again through the bath, to which a solution of stannic chloride has been added. Different shades are produced by the addition of logwood or fustic.

Logwood is chiefly used for dyeing greys and blacks. Formerly these colours were produced by means of salts of iron, but now *chrome black* is almost exclusively used for wool. The yarn is either first boiled with logwood and then passed into a hot solution of potassium dichromate, or the wool is first mordanted with chrome, and then dyed in a decoction of logwood and fustic.

A good black is obtained by boiling wool for an hour and a half in a solution containing 5 parts of potassium dichromate, 2 parts of copper sulphate, and 1 part of sulphuric acid, and leaving it over night in the bath. The dye bath consists of a decoction of 100 parts of logwood, 10 parts of fustic, and 11 of ammonia.

Logwood is also used for giving a violet shade to goods dyed in the indigo vat, the mordant being a tin salt.

Logwood black on silk is obtained by mordanting with ferric nitrate, and then dyeing in logwood liquor, to which fustic is added if a brownish black be wished for. Very often an indigo-blue ground is first dyed on the silk.

Fustic and *quercitron* were, before the artificial colours were known, the only yellow dyestuffs of importance which were used for the dyeing of wool and silk. They are fixed in a way very similar to that in use for cochineal; quercitron requiring the same mordants, while for fustic alum is used, generally with the addition of sulphuric acid, which prevents the colour going on the fibre too rapidly. This is essential for deeper shades, which else would become dull and patchy.

Fustic was, before the use of picric acid, generally employed for dyeing green on an indigo-blue ground.

It is also employed, as well as quercitron, for shading the colours produced by red woods, logwood and archil, and chiefly for the latter, with which it gives different bronze and olive shades.

The following proportions produce a bright and full yellow on 10 lbs. of wool:—Clear the water by boiling it with 4 ozs. of aluminium sulphate, then introduce 4 lbs. of quercitron, tied up in a bag, and 3 pieces of glue; boil one hour with the wool, remove the bag and add ½ lb. of aluminium sulphate, ½ lb. of tartar, and 1 lb. of tin chloride, which is prepared as follows:—To 55 lbs. of a solution of perchloride of tin at 110° to 115° Tw., add 5 lbs of tin crystals, and so much water that it stands at 38° Tw.

Orange tints are produced by adding cochineal.

Turmeric and *weld* serve principally for shading green and olive colours, while *annotta* is used in conjunction with fustic, red wood, cochineal, aniline red, &c., for different shades of yellow and orange.

Catechu-brown is produced on wool by passing it through a boiling decoction of catechu for some time, then adding to the bath a copper salt or potassium dichromate, and working the wool in it until it has acquired the proper shade.

Tannin-black on wool is obtained by using an iron salt as mordant, and then dyeing in a decoction of nut-galls, sumach, or any other astringent. The so-called *Sedan-black* is produced by imparting to the wool, first, a blue ground by the indigo vat, and then boiling it with sumach and logwood. It is then aired and brought back into the bath, to which some ferrous sulphate has been added. These operations must be repeated until the desired black is obtained. Sometimes copper sulphate is added to the bath, while, if a more brownish-black be desired, fustic is also used.

To obtain a good black on silk it is first galled in an infusion of nut-galls or sumach, and then worked in iron liquor. The silk thus treated becomes hard and rough; it is therefore worked in an emulsion, obtained by mixing caustic soda and oil, or in a soap solution.

A good black is also produced by mordanting with ferric nitrate, and passing successively through sumach liquor and soap solution. By repeating the mordanting and soaping, a very large quantity of ferric oxide is fixed by the silk. This is called *weighting*, and is necessary for good black silk, which without a certain amount of mineral matter would not possess that crispness which is required. However, the weighting of silk is often carried on too far, and becomes an adulteration. There is found black silk in the market leaving on incineration an ash amounting to 80 per cent. and more of the original weight. But it is not only black silk which is thus charged with mineral matters; the weighting is also carried out in the dyeing of other colours by charging the silk with stannic oxide, of which it can be made to take up a very large quantity by immersing it in a solution of stannic chloride, and keeping the liquid neutral.

A cheap black may be produced by mordanting silk twice with iron nitrate, and dyeing it in a decoction of logwood, to which some quercitron and blue vitriol has been added. The silk is then washed, and passed first through a solution of soap and then through a solution of basic acetate of lead. Thus the silk becomes weighted with a compound of lead with the fatty acids of the soap, and on exposing this to sulphuretted hydrogen black lead sulphide is formed.

Aniline black is also employed for the dyeing of silk and wool.

Prussian blue is generally fixed on wool by dissolving yellow prussiate of potash in water, adding one-fourth of sulphuric acid, and passing the wool into the solution, which is gradually heated from 60° to 90° C. The wool, which has now a bluish-green colour, is then passed through hot dilute sulphuric acid, to which some stannous chloride has been added to give a purple tinge to the blue. Since the introduction of aniline blue, Prussian blue is not much used for dyeing wool; not only because the former is a much more stable colour, but also because the dyeing of Prussian blue is a dangerous operation, on account of the prussic acid set free, which often overpowered the workmen if they did not take sufficient care.

The peculiar shade of Prussian blue is well imitated by the following process:—

10 lbs. of yarn are boiled for half an hour in a tinned vessel with ¾ lb. of alum, 1½ of tartar, and ½ lb of sulphuric

acid, at 130° Tw., and sufficient water. Then indigo carmine and a sufficient quantity of aniline violet is added.

Prussian blue on silk is obtained by mordanting it in ferric nitrate, to which sometimes stannic chloride is added, and working it in a solution of yellow prussiate. It is then washed and passed through dilute sulphuric acid.

After having discussed the principles on which the dyeing of wool and silk depends, the printing of woollen goods deserves a short notice.

The Printing of Wool.—Well washed and bleached wool always possesses a faint yellowish tint; but as in printed goods, bright colours appear only in all their purity if they are in contrast with a perfectly white ground, the first preparation which wool for printing has to undergo is to *dye* it *white*. This is done by passing it through a warm solution of soap, to which a little indigo carmine has been added. Thus the yellow and blue, being complementary colours, neutralize each other; and by varying the quantity of indigo carmine, greenish or bluish whites may be obtained. The wool is now placed in the sulphur chamber, and then passed through a warm solution of soda-ash. The next operation is *aluming*, or working the wool in a tepid solution of alum. The colours produced on wool by printing are all steam colours. The steaming is not only required for fixing the colours, but also to obtain pure and bright shades. Without steaming the colours are dull and unsightly.

The following examples will be sufficient for illustrating the methods which are used in the printing of wool:—

(*a*) *Aniline colours* are simply printed by using a thickened aqueous solution of the colour, and steaming the printed goods.

(*b*) *Logwood black* is produced by using a solution of the extract, to which is added copper sulphate or potassium chromate as oxidizing agent, alum and ferric nitrate as mordants, and oxalic acid to keep the combination of mordant and colour in solution, and thus enable it to penetrate the wool.

(*c*) *Cochineal reds* of varying shades are obtained by using either a decoction of cochineal or ammoniacal cochineal, to which stannic chloride and tartaric or oxalic acid are added.

(*d*) *Green* is obtained by using indigo carmine and extract of fustic, quercitron, or berries, together with alum, chloride of tin, and tartaric or oxalic acid. Fustic is generally used instead of quercitron, because it is cheaper, and the advantages which the latter has in dyeing are not so conspicuous in printing. Sometimes a little cochineal is added, to correct the greyness of the indigo blue.

(*e*) *Yellow* and *red Aurin* yield orange and red shades, which may be produced in different ways. Thus, on adding chloride of zinc to an alkaline solution of aurin, an orange lake is precipitated, which is fixed by mixing it with oxalic acid and gum, and steaming the goods after printing. Or aurin is mixed with calcined magnesia, water, and a little glycerin, and the colour fixed by steaming. Thus a fine red, a compound of magnesia and aurin, is obtained.

The Printing of Delaines.—Delaine is a mixed fabric, of which the warp is cotton and the weft wool. As these two materials possess such a different attraction for colours, great experience is required to obtain the two threads of the same shade. The colorist must be able to produce colour mixtures in which the colours do not interfere with each other, and which deposit uniformly both on the animal and the vegetable fibre. Cotton is best mordanted and dyed in neutral liquids, and at a moderate temperature; while on wool the colour fixes better at a high temperature, and in the presence of a little free acid. To equalize the attraction of the fibres as much as possible, they are always first impregnated with oxide of tin. Frequently the delaine colours are composed of two, one capable of fixing itself on the wool, and the other on the cotton.

A good example of such a colour is a mixture of steam Prussian blue for the cotton, and indigo carmine for the wool.

When delaine colours are unskilfully mixed, the two threads assume different shades, and threadiness is thus produced.

The Testing of Colours on Dyed and Printed Fabrics.—The detection of organic colours on dyed or printed goods is in some cases very easy, and in others very difficult. If only simple colours are present, a few tests are generally sufficient to determine the nature of the colour; but when the colour is a mixture of two or more bodies, it requires great practice to detect them.

In the following we give only those tests by which the more important colours may be distinguished from each other.

(1) RED COLOURS.

Rosaniline or *Aniline red* changes into yellow by moistening it with dilute hydrochloric acid, and becomes red again by washing with water. Dilute caustic soda bleaches it very slowly, and ammonium sulphide more quickly. Acetic acid restores the colour.

Saffranin becomes blue by treating it with strong hydrochloric acid: washing with water restores the colour. It is not changed by dilute caustic soda, and may thus be readily distinguished from *safflower*, which alkalies change into yellow, while dilute acids restore the colour.

Saffranin may also be detected by extracting it with alcohol, evaporating the solution to dryness, and treating the residue with sulphuric acid and water, as described under *Saffranin.*

Turkey red is readily recognized by its brilliant shade, and is distinguished from all other red colours by not being changed by dipping it for a few moments into a very dilute boiling solution of bleaching powder, by which all other reds are discharged. It is also not altered by dilute hydrochloric acid. By exhausting the tissue with ether, and evaporating the solution, a brilliant scarlet fat is left behind; and this, when boiled with strong caustic soda, yields a purplish-blue solution, from which acids precipitate alizarin in orange flakes. The fabric, after being treated with ether, exhibits a dull cherry-red colour.

Madder Red and Pink leave on incineration an ash which is rich in alumina. The colour is not discharged by boiling with soap and water. On treating the colour with dilute hydrochloric acid it becomes yellow, and after washing dilute caustic soda dissolves it with a purplish-blue colour. If this solution be not too dilute, pure alizarin may be obtained from it by adding dilute hydrochloric acid, and collecting the precipitate on a filter. The washed residue dissolves readily in alcohol, and on adding a solution of copper acetate a purple precipitate is obtained.

Brazil Wood, &c.—Tissues dyed by it or other red woods leave an ash containing alumina or tin oxide. A boiling soap solution changes the colour into yellow. By treating the colour, first with hydrochloric acid, and then with milk of lime, and passing through a solution of soap, a violet is produced, which soon disappears again. Concentrated sulphuric acid changes the colour into a bright cherry red, and dilute sulphuric into a bright orange; on boiling with a solution of aluminium sulphate, the liquid colours orange.

Cochineal red leaves also an ash containing tin oxide or alumina. Dilute caustic soda changes it into purple, and concentrated and dilute sulphuric acid into yellow. Boiling soap solution discharges the colour. On boiling with aluminium sulphate, a bluish-red solution is obtained.

Ammoniacal cochineal is not changed by dilute sulphuric acid.

PURPLE AND VIOLET COLOURS.

Hofmann's and Paris Violets are only slowly changed by alkalies; and if the colour be more or less discharged, it is restored by acetic acid. Dilute hydrochloric acid turns it yellow, but on washing with water the colour appears again.

Phenyl violets are not changed by dilute hydrochloric acid, but quickly discharged by dilute caustic soda; dilute hydrochloric acid restores the colour.

Mauve is not changed by dilute soda, and is turned into blue by strong hydrochloric acid.

Archil or French purple assumes a bluish tint, by treating it with dilute alkalies. Dilute acids change the blue into a red; ferric chloride weakens the colour, and gives it a yellowish tinge.

Madder purple and lilac leave an ash containing ferric oxide. The other tests are the same as for madder red.

Logwood blue or violet leaves an ash containing alumina. Dilute hydrochloric acid changes it into yellow or red, which by the action of aluminate of soda becomes blue again. On boiling with milk of lime, and then with soap, the colour is discharged. In boiling aluminium sulphate, it dissolves with a purple colour; when boiled with potassium dichromate the colour changes into brown or black.

ORANGE AND YELLOW COLOURS.

Yellow aurin on a tissue is changed, when boiled with soap, into a reddish shade; washing with water restores the colour. Dilute alkalies discharge the colour, a magenta-red solution being obtained. Lime water is coloured pink by it.

Annotta is changed into a bluish-green by boiling sulphuric acid; this test is best effected by exhausting the colour with alcohol, evaporating solution to dryness, and treating the residue with the acid.

Picric Acid.—The wool or silk is exhausted with hot dilute ammonia, and the deep-yellow solution concentrated on a water bath; on adding potassium cyanide to the residue, a blood-red colour is produced.

Naphthalene yellow gives almost the same reactions; but it can be distinguished from picric acid by heating with ammoniacal copper solution and washing. The colour of naphthalene yellow is then changed into olive green, and picric acid into bluish green.

Turmeric becomes brown by moistening it with dilute soda; acids restore the colour. On moistening the colour with a solution of boric acid, and drying, it becomes orange; and by treating it now with dilute soda it becomes blue, which soon changes into a dirty grey.

Fustic.—When boiled with aluminium sulphate, a yellow solution is obtained, showing a strong bluish-green fluorescence. The colour becomes very dark by treating it with a dilute boiling soap-solution, while *quercitron*, *Persian berries*, *and weld* do not change; but on boiling with stannous chloride, then the colour changes into orange.

(2) BLUE COLOURS.

Aniline or *Phenyl blue* gives the same reactions as phenyl violet. The colour is soluble in boiling alcohol and acetic acid, and is discharged by bleaching powder. It is not dissolved by boiling aluminium sulphate.

Aniline blue is often mixed with indigo or indigo-sulphuric acid. To analyze such a mixture boil the tissue with alcohol, which dissolves the aniline blue. Then boil the same portion with aluminium sulphate, which dissolves only the indigo-sulphuric acid. If the cloth still remains blue, it indicates the presence of indigo.

Indigo is neither changed by alkalies nor hydrochloric acid, nor soluble in hot alcohol, but dissolves a little in boiling glacial acetic acid. Bleaching powder discharges the colour.

Indigo-sulphuric acid is coloured brown or yellow by cold ammonium sulphide.

Prussian blue is not changed by acids, but readily by alkalies, the residue on the cloth consisting of ferric oxide, while the solution contains a ferrocyanide, which can be detected by adding hydrochloric acid and ferric chloride.

(3) GREEN COLOURS.

Aniline or *Iodine green* dissolves in strong hot alcohol. On boiling it with dilute hydrochloric acid it turns blue or purple. Potassium cyanide bleaches the colour.

The other green colours are generally mixtures of aniline or Prussian blue, or indigo, with yellow colours. They may be tested as follows:—

Boil with strong alcohol.

(*a*) The alcohol is coloured yellow and the tissue blue. Indigo or Prussian blue is present. The residue is washed and tested for these colours as already indicated. The alcohol is also tested for yellows as directed above.

(*b*) The alcohol is coloured green; aniline blue is present. Boil another part of the substance with dilute hydrochloric acid: it will change into blue, and a yellow solution is obtained, which is examined for the yellows.

Black Colours.—Aniline black is recognized by its peculiar velvety tint. It is not changed by alkalies; acids change it into a dark green; alkalies restore the colour. Bleaching powder turns it into a garnet red.

Madder black is tested like madder purple.

Logwood black leaves an ash containing either ferric oxide or chromic oxide. It is coloured red by hydrochloric acid, and blue on the subsequent treatment with aluminate of soda. Bleaching powder discharges the colour.

Tannin black leaves a residue of ferric oxide, and is discharged by hydrochloric acid; the residue gives neither the tests for logwood nor madder.

Natural and Artificial Alizarin.—J. Weber states that if the tissue is steeped in permanganate of potash, and then in an acid solution, the red produced by extract of madder turns a reddish-yellow, whilst that produced by artificial alizarin becomes a rose colour. Or, by treating the cloth successively with potassium dichromate and nitric acid, the madder red is discharged, whilst alizarin red still retains some colour. If then boiled in soda liquor of 18° Beaumé, washed, and dipped in hydrochloric acid at 20° B., alizarin red becomes a light yellow, but madder red a dirty orange.

The swatches are dipped in a solution of 1 gramme of permanganate of potash in 200 cc. of water, and are then washed, and plunged into hydrochloric acid at 3° B., again washed, and a second time dipped in the permanganate of potash, after which they are washed and passed through oxalic acid at 1° Beaumé. Or, the swatches are steeped in a solution containing 10 grammes of bichromate of potash in 200 grammes of water, drained, passed through nitric acid at 6° B., and washed.

Professor W. Stein has published the following analytical tables for the detection of the different organic colours on tissues:—

RED COLOURS.

<table>
<tr><th>Heat with Ammonium Sulphide.</th><th colspan="7">Boil with a Solution of Aluminium Sulphate.</th></tr>
<tr><td rowspan="2">The colour changes into greenish or bluish.</td><td rowspan="2">The liquid colours red, and shows a beetle green reflection.</td><td colspan="6">The liquid becomes red without showing a reflection. On adding an equal volume of acid sodium sulphite—</td></tr>
<tr><td colspan="4">It is bleached</td><td colspan="2">It is not bleached</td></tr>
<tr><td rowspan="11"><i>Aloes purple;</i> may be confirmed by boiling with baryta water, which changes the colour into green. If at the same time the liquid becomes purple, archil is also present.</td><td rowspan="11"><i>Madder.</i></td><td colspan="4"><i>Brazil wood, santal, magenta, corallin, safflower.</i></td><td colspan="2"><i>Cochineal, lac-dye, kermes, archil.</i></td></tr>
<tr><td colspan="4">Boil with alcohol of 80 per cent.</td><td colspan="2">Boil with alcohol.</td></tr>
<tr><td colspan="2">The liquid colours distinctly</td><td colspan="2" rowspan="2">Liquid colours but little or not at all.</td><td rowspan="2">Liquid becomes red.</td><td rowspan="2">Does not colour, or only faintly.</td></tr>
<tr><td>bluish red.</td><td>yellowish red.</td></tr>
<tr><td rowspan="7"><i>Magenta.</i></td><td rowspan="7"><i>Santal;</i> is changed by lime water to brown, and it colours hot acids red.</td><td colspan="2"><i>Brazil wood, corallin, safflower.</i></td><td><i>Archil.</i></td><td><i>Cochineal, lac-dye, kermes.</i></td></tr>
<tr><td colspan="2">Heat with lime water, which shows,</td><td colspan="2">Heat with baryta water.</td></tr>
<tr><td>No colour.</td><td>Red colour.</td><td>Liquid remains colourless.</td><td>Liquid becomes red.</td></tr>
<tr><td><i>Safflower.</i></td><td><i>Brazil wood, corallin.</i></td><td><i>Lac-dye.</i></td><td><i>Cochineal, kermes.</i></td></tr>
<tr><td colspan="2">Heat with dilute sulphuric acid.</td><td colspan="2">Heat with lime water.</td></tr>
<tr><td>Tissue colours orange.</td><td>Tissue turns yellow.</td><td>Tissue colours, brownish red.</td><td>Tissue becomes violet.</td></tr>
<tr><td><i>Brazil woods.</i></td><td><i>Corallin.</i> Copper chloride changes the colour into grey.</td><td><i>Kermes.</i></td><td><i>Cochineal.</i></td></tr>
</table>

VIOLET AND PURPLE COLOURS.

HEAT WITH AMMONIUM SULPHIDE

- Tissue is bleached.
  - *Soluble aniline violet, magenta with indigo carmine.*
  - Boil with alcohol, which colours
    - Violet.
      - *Soluble violet.*
    - Red.
      - *Magenta.*
- Tissue colours brownish red.
  - *Mauve, Hofmann's violets.*
  - Add cold dilute hydrochloric acid, which colours
    - Yellowish.
      - *Hofmann's violet.*
    - Purple.
      - *Mauve.*
- Turns olive brown
  - *Alcannet.*
- Hardly any change.
  - *Archil, ditto with indigo, logwood, madder.*
  - Boil with alcohol.
    - Liquid colours pink or brown; ammonia changes it into violet.
      - *Archil*, with or without *indigo*. If indigo is present, hot chloroform will colour blue.
    - Liquid remains almost colourless.
      - Heat with dilute hydrochloric acid, which colours
        - Red.
          - *Logwood;* if indigo be present, hot chloroform will colour blue.
        - Not, or yellow.
          - *Madder.*

YELLOW COLOURS.

HEAT WITH A DILUTE OR ALCOHOLIC SOLUTION OF NEUTRAL FERRIC CHLORIDE.

- The colour is not, or only very little, altered.
  - *Annotta, turmeric, aniline yellow, picric acid, naphthalene yellow.*
  - Place one drop of concentrated sulphuric acid on tissue.
    - A blue or green spot is produced.
      - *Annotta.*
    - The spot becomes at once, or after some time, more or less brown or red.
      - *Turmeric, aniline yellow, picric acid, naphthalene yellow.*
      - Add alcohol, with a few drops of hydrochloric acid and some boric acid.
        - Liquid colours
          - Intensely pink.
            - *Turmeric.* On adding an equal volume of water both liquid and tissue colour reddish-yellow.
          - Pale pink.
            - *Aniline yellow.* Tissue colours violet, and on adding water, crimson; while the liquid assumes a deeper colour.
        - No change.
          - *Picric acid, naphthalene yellow.*
          - Heat with an ammoniacal copper solution, and wash.
            - Colour changes into
              - Bluish-green.
                - *Picric acid.*
              - Olive-green.
                - *Naphthalene yellow.*
- Tissue colours more or less yellowish-green, olive-green, brown, or almost black.
  - *Madder yellow, fustic, fustet, quercitron, flavin, berries, weld.*
  - Boil with aluminium sulphate, and add an equal volume of water.
    - Liquid becomes red, and has a green reflection.
      - *Madder-yellow;* contains tin as mordant.
    - Liquid yellow, with a bluish-green reflection.
      - Fustic.
    - Liquid yellow, without reflection.
      - *Fustet, quercitron, flavin, berries, weld.*
      - Heat with baryta-water or lime-water.
        - Tissue colours red.
          - *Fustet.*
        - Tissue colours a little darker.
          - *Quercitron, flavin, berries, weld.*
          - Boil with glacial acetic acid; after cooling, the solution shows—
            - A distinct green reflection.
              - *English flavin.* The liquid is yellow.
            - No, or only a faint reflection, and is hardly coloured.
              - Boil with basic lead acetate.
                - Colour of tissue scarcely changed.
                  - *Weld.*
                - Tissue colours orange-brown.
                  - *Quercitron, berries.*

BLUE COLOURS.

Heat with alcohol of 80 per cent., and a few drops of hydrochloric acid.		
Liquid and tissue become red.	Tissue remains blue; liquid colours blue.	No change.
Logwood.	*Aniline blue*, or *indigo-sulphuric acid.*	*Indigo*, or *Prussian blue.*

Put one drop of strong sulphuric acid on the tissue.	
No change.	Colour changes into a yellowish or reddish brown.
Indigo-sulphuric acid.	*Aniline blue.*

Heat with a solution of sodium carbonate.	
No change.	Colour becomes yellow or brown.
Indigo.	*Prussian blue.*

GREEN COLOURS.

I. Boil with a moderately concentrated solution of potassium cyanide.	
Colour changes into brown or yellow.	Does not change, or changes into a brownish or yellowish green.
Aniline green, green containing *indigo-sulphuric acid (carmine green).*	*Green.* containing *indigo* with or without *carmine green.*

II. Add to solution thus obtained an equal volume of water, and then a solution of aluminium sulphate, until an abundant precipitate is formed; but avoid an excess. Filter and wash.

Filtrate is yellow or reddish.	Filtrate is blue; precipitate after washing is :—		Filtrate colourless, precipitate yellow.	Filtrate blue.
Aniline green.	Colourless.	Yellow.	Only *indigo.*	*Indigo-sulphuric acid.*
	Carmine green, with *picric acid.*	*Carmine green*, with a *vegetable yellow.*		Precipitate is—

Precipitate is—	
Colourless	Coloured
Picric acid.	*Vegetable yellow.*

Proceed as in III.

III. Dissolve yellow precipitate in water, add a little sulphuric acid, and filter.	
Solution has a green fluorescence.	No fluorescence.
Fustic.	*Weld, turmeric.*

Heat another portion with alcohol, add boric and hydrochloric acids.	
Liquid colours.	
Pink.	Not.
Turmeric	*Weld.*

BIBANOW has also lately investigated the reactions of similar colours—viz., HOFMANN'S violet, Paris violet, dimethylaniline-violet, diphenylamine-blue, methyldiphenylamine blue, iodine green, dimethylaniline green, saffranin, and magdala red.

With these colours he dyed patterns of silk, wool, and cotton. The silk was not mordanted, excepting that dyed with iodine green, which was fixed by tannin. The wool was also only mordanted with sulphur (*i.e.*, sodium hyposulphite and dilute sulphuric acid) for dyeing the two greens. The mordants for cotton were tannin and albumin. Diphenylamine- and methyldiphenylamine- blue were dyed in an alcoholic solution without mordants. The reagents which BIBANOW used were—acetic acid of spec. grav. 1·056; hydrochloric acid of spec. grav. 1·160; nitric acid of spec. grav. 1·245; chromic acid solution (1 : 20); caustic soda of spec. grav. 1·085; solution of sodium sulphide (1 : 10); solution of stannous chloride (1 : 10); solution of ferric chloride

(1 : 10); solution of bleaching powder (1 : 10), and common ammonia.

He moistened by means of a glass rod the different samples, and after some time washed them with water. In the following tables, the sign 0 means that no change has taken place.

HOFMANN'S VIOLETS.

Reagents.	Cotton Mordanted With Albumin.	Cotton Mordanted With Tannin.	Wool.	Silk.
	Fine bluish violet.	Same.	Same.	Dahlia purple.
Acetic acid.	Blue, after washing, original colour.	Same.	Same.	Same.
Hydrochloric acid.	Pale yellow; on the margin green or blue; on washing, green, blue, and at last violet.	Same.	Same.	Same.
Nitric acid.	Pale yellow; on washing, blue, green, and violet.	Same.	Pale yellow.	Same.
Chromic acid.	Yellowish-brown; on washing, pale violet.	Same.	Brown.	Brown.
Soda.	Gradually a dirty grey; after washing, pale violet.	Brown; after washing, light grey.	Brown; washing restores the original colour.	Violet, then reddish violet; washing restores the colour.
Ammonia.	0	0	0	0
Sodium sulphide.	Gradually changed into light grey.	Same.	Gradually bleached.	Gradually bleached; on washing again, violet.
Stannous chloride.	Blue; after washing, pale violet.	Greenish blue; after washing blue.	Blue.	Blue; after washing, violet.
Ferric chloride.	Blue; after washing, original colour.	Bluish-green; after washing, black.	0	Blue; after washing, violet.
Bleaching powder.	Gradually bleached.	Same.	Slowly changed into pale grey.	Same.

POIRIER'S METHYL VIOLET

Reagents.	Cotton Mordanted With Albumin.	Cotton Mordanted With Tannin.	Wool.	Silk.
Acetic acid.	0	0	0	0
Hydrochloric acid.	Pale yellow, with green and blue margin; on washing, bluish-green and then violet.	Same.	Same.	Same.
Nitric acid.	Pale yellow; on washing, green, blue, and then violet.	Same.	Same.	Same.
Chromic acid.	Yellowish-brown; after washing, pale yellow.	Same.	Same.	Same.

POIRIER'S METHYL VIOLET—(*Continued*).

Reagents.	Cotton Mordanted		Wool.	Silk.
	With Albumin.	With Tannin.		
Soda.	Gradually light brown; after washing, pale violet.	Brown; after washing, pale violet.	Brown; after washing reddish-violet.	Gradually pale grey; after washing, original colour.
Ammonia.	0	0	0	0
Sodium sulphide.	Pale grey.	Same.	Gradually bleached.	Gradually pale grey; after washing, violet.
Stannous chloride.	Blue; after repeated washing, violet.	Blue.	Blue.	Blue.
Ferric chloride.	Green; after washing, original colour.	Black.	Greenish - grey; after washing, original colour.	Blue; after washing, original colour.
Bleaching powder.	Bleached.	Same.	Slowly bleached.	Gradually bleached.

POIRIER'S DIMETHYLANILINE VIOLET.

Reagents.	Cotton Mordanted		Wool.	Silk.
	With Albumin.	With Tannin.		
	Bright purple.	Bright purple.	Violet, with a faint greyish tint.	Rich purple.
Acetic acid.	0	0	0	0
Hydrochloric acid.	Pale yellow; margin green or blue; on washing, green, blue, and at last, violet.	0	Same.	0
Nitric acid.	Pale yellow; on washing, green, blue, and violet.	Same.	Pale yellow.	Like cotton.
Chromic acid.	Yellowish-brown; after washing, pale yellow.	Same.	Yellowish brown.	Brown.
Soda.	Gradually pale brown; after washing, pale violet.	Brown; after washing, pale violet.	Brown; after washing, violet.	Gradually greyish violet; washing restores the original colour.
Ammonia.	0	0	0	0
Sodium sulphide.	Pale grey.	Pale grey.	Gradually bleached.	Gradually pale grey; washing restores the colour.
Stannous chloride.	Blue.	Blue.	Blue; washing restores the colour.	Same.
Ferric Chloride.	Greenish blue; washing restores the colour.	Greenish blue; after washing, black.	Grey; washing restores the colour.	Greenish-blue; washing restores the colour.
Bleaching powder.	Gradually bleached.	More quickly bleached.	Slowly, but completely bleached.	Same.

DIPHENYLAMINE BLUE.

REAGENTS.	COTTON, DYED IN AN ALCOHOLIC SOLUTION.	WOOL.	SILK.
	Greyish-blue.	Blue, with a greyish tinge.	Same.
ACETIC ACID.	0	0	Colour more bright.
HYDROCHLORIC ACID.	0	0	0
NITRIC ACID.	Gradually grey.	Dark, dirty green.	Yellowish grey.
CHROMIC ACID.	Greenish - yellow; after washing, grey.	Brown; after washing, greenish-yellow.	Greenish-yellow.
SODA.	Gradually discoloured; washing restores the colour.	Very slowly changed into grey.	Like cotton.
AMMONIA, SODIUM SULPHIDE, AND STANNOUS CHLORIDE.	0	0	0
FERRIC CHLORIDE.	Green; washing restores the colour.	Same.	Same.
BLEACHING POWDER.	Very slowly bleached.	Same.	Same.

METHYLDIPHENYLAMINE BLUE (PREPARED WITH OXALIC ACID).

REAGENTS.	COTTON, DYED IN AN ALCOHOLIC SOLUTION.	WOOL.	SILK.
	Beautiful blue.	Blue with greenish tinge.	Beautiful blue.
ACETIC ACID.	0	0	0
HYDROCHLORIC ACID.	0	Violet; washing restores the original colour.	0
NITRIC ACID.	Brownish - black; after washing, dark green.	Brownish-black in reflected light, and a dark reddish-violet in transmitted light; after washing, dirty blue.	Like wool; but after washing, yellowish-green.
CHROMIC ACID.	Same as nitric acid.	Same; after washing, dirty blue.	Black; after washing, dirty green.
SODA.	Grey; after washing, original colour.	First, reddish- violet, then dirty orange, and at last yellow.	Reddish - violet; after washing, blue.
AMMONIA.	0	Pale green; after washing, blue.	Same.
SODIUM SULPHIDE.	Colour becomes pale.	Green, greenish-yellow, pale yellow; on washing, blue.	Same.
STANNOUS CHLORIDE.	0	0	0
FERRIC CHLORIDE.	Greenish-blue; washing restores the colour.	Green; washing restores the colour.	Same.
BLEACHING POWDER.	Slowly, but completely bleached.	Gradually green; after washing, greenish-blue.	Changes gradually into yellowish-grey.

IODINE GREEN.

REAGENTS.	COTTON MORDANTED		WOOL.	SILK.
	WITH ALBUMIN.	WITH TANNIN.		
	Bright green.	Somewhat bluish-green.	Bluish-green.	Very pure green.
ACETIC ACID.	Bluish-green.	Bluish-green.	0	Bluish-green; washing restores the colour.
HYDROCHLORIC ACID.	Yellow; after washing, green.	Same.	Same.	Same.
NITRIC ACID.	Like cotton.	Same.	Yellow.	Yellow.
CHROMIC ACID.	Yellowish-brown; after washing, pale yellow.	Same.	Same.	Same.
SODA.	Pale yellow; after washing, colourless.	Same.	Same.	Same.
AMMONIA.	Bluish-green.	Same.	Paler.	Paler.
SODIUM SULPHIDE.	Bleached.	Same.	Same.	Same.
STANNOUS CHLORIDE.	Yellowish-green.	Same.	0	0
FERRIC CHLORIDE.	Yellowish green; washing restores the colour.	Black.	0	Black (tannin being present).
BLEACHING POWDER.	Gradually bleached.	Same.	Incompletely bleached.	Gradually bleached.

DIMETHYLANILINE GREEN.

REAGENTS.	COTTON MORDANTED		WOOL.	SILK.
	WITH ALBUMIN.	WITH TANNIN.		
	Pale greyish-green.	Bright green.	Bluish-green.	Bright green.
ACETIC ACID.	Bluish green.	Same.	0	Bluish-green.
HYDROCHLORIC ACID.	Yellow; after washing, green.	Same.	Same.	Same.
NITRIC ACID.	Like hydrochloric acid.	Same.	Yellow.	Yellow.
CHROMIC ACID.	Yellowish-brown; after washing, pale yellow.	Same.	Yellowish-brown; after washing, greenish-yellow.	Same as wool.
SODA.	Flesh-colour, then pale yellow; after washing, almost colourless.	Same.	Colour becomes very much paler, and disappears on washing.	Like cotton with albumin.
AMMONIA.	Paler.	Paler.	Colourless; after washing, green.	Paler.
SODIUM SULPHIDE.	Bleached.	Bleached.	Only completely bleached after washing.	Same as wool.
STANNOUS CHLORIDE.	Yellowish green; colour restored by washing.	Yellowish green.	0	Yellowish-green.
FERRIC CHLORIDE.	Like stannous chloride.	Black.	0	Like cotton with albumin.
BLEACHING POWDER.	Bleached.	More slowly bleached.	Only slowly and incompletely bleached.	Gradually bleached.

SAFFRANIN.

Reagents.	Cotton Mordanted		Wool.	Silk.
	With Albumin.	With Tannin.		
	Beautiful, but not intense crimson.	Intense crimson.	Intense crimson.	Beautiful, but not intense crimson.
Acetic acid.	Colour becomes brighter, but after washing it appears unaltered.	Same.	0	0
Hydrochloric acid.	Blue, after washing red again.	Same.	Same.	Same.
Nitric acid.	Like hydrochloric acid.	Same.	Same.	Same.
Chromic acid.	Yellowish-brown.	Same.	Same.	Yellowish-red.
Soda.	0	0	0	0
Ammonia.	0	0	0	0
Sodium sulphide.	Yellowish-red; after washing, original colour.	Yellowish-brown.	0	0
Stannous chloride.	Yellowish; after washing, pale red.	0	0	0
Ferric chloride.	Yellowish-brown; after washing, red.	Blackish-brown.	0	0
Bleaching powder.	Brown, grey, yellow, and at last colourless.	Same.	0	Gradually bleached.

MAGDALA RED.

Reagents.	Cotton Mordanted		Wool.	Silk.
	With Albumin.	With Tannin.		
	Bright pink.	Pink, having a faint purplish tinge.	Like cotton, with tannin.	Bright pink.
Acetic acid.	0	0	0	Colour more vivid; but after washing, original shade.
Hydrochloric acid.	0	0	0	Brighter.
Nitric acid.	Grey, yellowish-grey, yellowish; after washing, yellowish-red.	Same.	Grey, then yellowish; after washing, yellow.	0
Chromic acid.	Yellow; after washing, pale.	Same.	Yellow.	Yellow.
Soda, ammonia, sodium sulphide, and stannous chloride.	0	0	0	0
Ferric chloride.	Brown.	Black.	0	0
Bleaching powder.	Quickly bleached.	Same.	Gradually bleached.	Same.

The two samples of cotton were dyed in an alcoholic solution.

The most practical method of estimating the value of a dye stuff, is to dye a certain given shade on a weighed quantity of wool, silk, or cotton, and compare the quantity of colour used with a standard colour.

Thus an aniline colour may be tested in the following way:—

5 decigrammes of the colour are dissolved in warm spirits of wine, and when cold, the solution is made

up to 50 c.c. Heat now in a porcelain basin some water nearly to the boiling point; add one gramme of white best wool, and let it get thoroughly wetted; remove it with a glass rod, and add to the water 1 to 2 c.c. of the colour; mix well and dye the wool in this solution. When it has taken up all the colour, add gradually more until it attains the proper shade. Suppose now that 7 c.c. were required to produce the same shade as 5 c.c. of the standard colour, then the value of the colour will be $\frac{5}{7}$ of the standard.

In a similar way most other colours may be tested, as for instance, flavin, cochineal, &c. A proper dye-bath is made containing a given weight of colour; in a portion of it a given weight of wool is dyed, and gradually more colour is added until the proper shade has been attained.

If metric weights or measures are not at hand, grains and fluid grains are used. Thus in the above example 10 grains of the colour are dissolved in 100 fluid grains of spirits, and with this solution 20 grains of wool are dyed by adding gradually to the boiling water the solution of the colour, as described above.

Calico Printing.—Calico (from Calicut, a town in Northern India), is a kind of cloth made entirely from cotton; but the term calico printing has usually a broader meaning than simply printing calico, and is generally applied to the printing of any kind of tissue used for garments, whether made from cotton alone, or mixed with other fibres, or made of linen, wool, or silk.

Historical.—A few passages occur in ancient writers which, though vague and general, make it certain that there existed in very remote times, say 2000 B.C., some method of colouring cloth with designs representing figures of plants and animals; but it is only in PLINY that there is any distinct reference to the methods employed, and he describes in a dozen lines the dyeing of mordanted cloth, as seen by him practised in Egypt, in very much the same terms that an intelligent but non-technical observer might describe at this day the operations of a madder dye house. The only remains of ancient textile fabrics which have been preserved to modern times are the wrappings of mummies. These are shown to be made of linen, and not of cotton; and though Mr THOMPSON of Primrose proved tolerably well that both indigo and safflower had been used to dye some portions of mummy cloth, no appearances of printing have been discovered on these wrappings. All printed textile fabrics are in their nature so perishable and intrinsically of so little value, that it is not surprising that there are very few examples of them to be found bearing old dates. Nevertheless we are not quite without illustrations of respectable antiquity. In the South Kensington Museum there is a very early and rare specimen of block-printed silk of the thirteenth century, of Sicilian origin (No. 1251); there are also several specimens of Flemish block-printed linens ascribed to the fourteenth century; and an example of Byzantine printing on a mixed cotton and silk tissue of the same date. No doubt the art of printing or painting designs on cloth was always practised more or less in civilized communities where textile fabrics were manufactured; and we may conclude that in the middle ages Sicily, Italy, and Flanders were countries where the process was carried on, and whence it spread to other places. The introduction of calico printing into England was stated by THOMPSON to date from 1690, when a Frenchman, supposed to be one of the Huguenot refugees, established a small work on the Thames at Richmond. This statement was adopted by BAINES in his history of the cotton manufacture, and is repeated with additions by POTTER, PERSOZ, and every other writer upon this subject. But it will be seen that there are no grounds for this supposed introduction by a Frenchman, and that printing was practised in England at much earlier dates than 1690. The Edict of Nantes was revoked by LOUIS XIV. in 1685, and DOLLFUS AUSSET, in remarking upon THOMPSON's statement, says that if it be true that the exiled Huguenots introduced printing into England or elsewhere, they must have learned their business somewhere out of France, for there were no printworks in France before the year 1746, when the KŒCHLINS established their firm at Mulhouse, and they received their knowledge of blocks and mordants from Hamburg. In the South Kensington Museum there is a specimen of English block-printed chintz of early date, No. 1622, and CANON ROCK believes that still earlier specimens are to be found in the chapter library at Durham. The very earliest account known of printing shows that the art was practised in England before the year 1410; it is to be found in manuscripts preserved in the Bibliothèque Royal in Paris, some of which have been printed, and some translated by Mrs. MERRIFIELD in her work on painting. In the manuscript of JEHAN DE BEGUE, under date of 11th February, 1410, there is an account in old French given by one THEODORE, a native of Flanders, to JOHANNES ALCHERIUS, of the composition of certain topical colours, which the said THEODORE had himself made and used in England for painting upon cloth, probably of linen. These colours are composed of materials and would produce effects similar to those in use for low-class printing at this day; iron liquor, alum, brazil wood, kermes, walnut peel, galls, indigo, lime, honey, and orpiment are prescribed. None of the recipes give any thickening matters, and it may be gathered that these dyes were applied by a brush or pencil upon cloth prepared with gum water. The earliest English patent referring to printing is dated 1619, and there are others in 1675, 1676, and 1692, which clearly show that printing was a business well known and practised in England before the Huguenot exodus took place; this, with the previous evidence, leads to the belief that it was introduced into England from Flanders some time in the fourteenth century.

Like most other industries, that of calico printing had to struggle against mistaken fiscal regulations. Not only the importation, but the home manufacture of cotton prints, was for a time interdicted to serve the interests of other manufactures. Later on, the printing of calico was permitted under a heavy duty, which was reduced eventually to 3½*d.* per square yard, equivalent to 5*s.* per piece on all the calico printed in the last year of the imposition of this duty, which was 1830, when the amount obtained was £1,897,265 7*s.* 1*d.* (POTTER *On Copyright*, 1840.)

The history of calico printing from that date is to be found in the following pages in connection with the various processes and machines employed.

The practical treatment of the subject of calico printing as a manufacture may be conveniently divided into the following sections:—

1. Processes preparatory to Printing; these include marking, singeing, bleaching, and shearing, with winding on.
2. Printing Processes; including the various means by which the design is reproduced upon the cloth by pencilling, stencilling, block printing, and cylinder printing, with a few special methods.
3. Preparation of the colours for printing, embracing the routine of the colour house, and a study of thickeners and mordants.
4. Treatments of the cloth after printing, to fix or develop the colour, amongst which are ageing, steaming, chroming, &c.
5. Dyeing processes, including dunging, soaping, washing, and clearing.
6. Finishing processes, including starching, stretching, mangling, degging, and calendering.

On the Marking of the Grey Calico.—In the management of a print works, it is desirable to be able to trace backwards the course of any given piece of calico. To this end the first process is to stamp every lot of cloth with some number or distinctive mark. The best substance at present known is gas tar; most oil colours, as red lead paint, printers' ink, or common black paint can be used, and will leave sufficient traces upon the cloth after bleaching, but there is nothing known which will stand the bleaching processes in a perfect manner. Aniline black comes out perfectly distinct under favourable circumstances, but it is uncertain and unmanageable. In the last century HAUSMANN investigated the subject, and after trying copal varnish with pigments, which stood pretty well, recommended manganese salts fixed by alkali, as capable of withstanding all the bleaching operations. The application of a fixing agent would be highly inconvenient, and the process was probably never put into practice. Weft dyed in manganese brown has been used as a heading, but it is not permanent, often disappearing completely before the end of the bleaching.

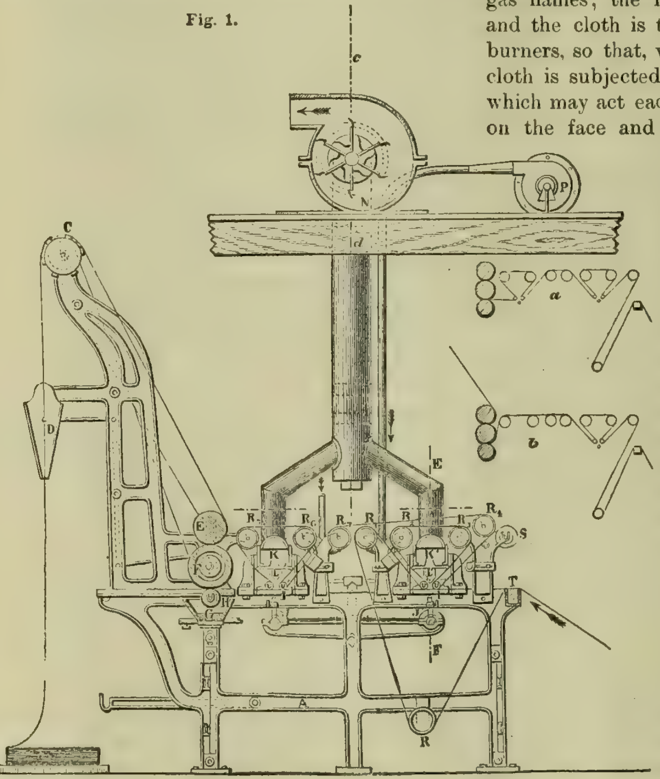
Sewing of the Pieces for Bleaching.—A loose strong stitch is required. The quality of the thread is of importance; for the breaking out of an end in bleaching entails great loss of time and interruption to the process. Hard thread may cut the cloth in the squeezers, and should be avoided.

SINGEING.—This is the first manufacturing operation in a print works. It is known also under the names of firing, dressing, and perhaps some others; the object is to remove the numerous ends of cotton hairs which can be seen when a piece of grey calico is held on a level with the eyes. If these hairs were left on they would interfere seriously with the printing operations. A well-singed cloth receives the colours impressed upon it directly on the warp and weft threads which form the tissue; and nothing short of the turning of these threads in the after operations will disturb the clear outline and uniformity of shade of the finest line. On an unsinged cloth the result is different; the colour is deposited in part upon the shifting hairs. So long as these hairs remain where the printing operation has fixed them no considerable defect is to be observed; but when the cloth comes to be wetted, the hairs float about to the extent of their tether, and upon drying occupy different places—the coloured ones lying over the white, and the white ones over the coloured places of the print, blurring the outline, and destroying all clearness and sharpness of effect. In dark-ground prints defective singeing is very injurious, since it usually happens that the unsinged hairs are less coloured than the body of the cloth, and destroy the uniformity of the dark colour. Nevertheless there are some styles of coarse prints in which it is nearly indifferent whether the cloth be singed or not, and there are other styles in which a good full face on the calico is more valued than clearness of outline. For such styles singeing may be omitted, but for all better class styles it is indispensable.

No mechanical method of removing these hairs in a satisfactory way has been discovered; they have not sufficient resistance to be cut off by any shearing process; and as the term *singeing* expresses, they are burnt off by some one of the arrangements afterwards to be described. The methods of singeing are—(1), by red-hot plates; (2), by flame of gas, alcohol, or other combustible; and (3), by a combination of flame and red-hot plate. The ordinary singeing stove consists of a long and narrow fire-grate, covered over with a copper plate, which is bent to a curvilinear form; the fire heats this plate red hot, and the cloth is drawn over it, and in contact with it, in a swift and regular manner. A drawing of a singe plate is given at p. 367, BLEACHING. One passage over such a plate does not generally singe cloth sufficiently well. If the plate could be kept at a uniform bright red heat, a single passage might be enough; but that is hardly possible on account of the rapid cooling action of the cloth upon the metal, which soon reduces the temperature below the singeing point. When the plate is long enough to allow the cloth to be traversed from the cooled part to a hotter part, and then back again, something can be done by a skilful man; but the general result of such treatment is uneven singeing, one edge of the piece singed and the other half singed. And yet it is very undesirable to singe twice over, on account of not only the labour, but the danger of fire. To meet this difficulty two plates can be arranged side by side, and may be heated by the same fire, either directly, or the flue from the fire under one plate can be led round under the other; in this case, one plate is usually much less heated than the other.

The best arrangement is to heat each plate by a separate fire, so that both can be kept at a proper singeing heat. For it is probable that passing the piece across a dull red or, as it often occurs with bad stoves, over a black plate, does no good at all, but rather harm, by flattening down the hairs, which are then not so readily burned by the second plate. The speed with which the cloth should pass across the plates depends upon the degree of heat of the plates, and provision should be made for varying the speed. The most convenient way of doing this is by driving with an independent small engine, but there are other well-known means of doing it from gearing. Two plates in good order will singe cloth at the rate of from 120 to 150 yards per minute, two pieces in width being singed at the same time. A singe of this description answers for good ordinary prints. But sometimes much more labour and care is given to the singeing. In the case given, only one side of the piece is singed, but many singe both sides, and sometimes the cloth is sent three times across the plates—twice on the side intended to be printed, and once on the back of the piece.

Fig. 1.



Gas Singeing.—Soon after the introduction of gas for illuminating purposes it was applied to singeing calico. Hall's patents are dated 1818 and 1823; his process consisting in drawing the cloth through a gas flame, the action of which was assisted by a chimney over the flame. Many modifications of the original plan were carried into practice, but without any marked success. The chief complaint was, that when the cloth was fairly well singed, it was at the same time much impoverished, owing to the gas flame penetrating the tissue and burning the threads, making them thinner and weaker. It was evident that this could be prevented by making the cloth pass over, and in close contact with, a metallic surface while the gas flame played against it. The difficulty here consisted in getting a proper combustion of the gas, and this was attempted more or less successfully by mixing air with the gas. Probably the best arrangement for singeing yet produced is that of Tulpin, Fig. 1, patented in England in 1862. It consists essentially of two rows of ordinary gas-burners, each row the width of the piece to be singed. The cloth is brought in contact with the flame by means of two metal rollers of small diameter, and near to one another, one on each side of the row of gas flames; the flame passes between the rollers, and the cloth is twice singed by each row of gas-burners, so that, with two rows of gas-burners, the cloth is subjected four times to the singeing flame, which may act each time on the same side, or twice on the face and twice on the back. The steady burning of the gas is secured by an exhaust fan, P, properly connected with the burners by tubes, and the products of combustion are at the same time carried away in a very perfect manner.

Fig. 1 shows the construction of this apparatus, and how it may be threaded to give different kinds of singeing. The rows of gas burners are supported on the arm, J J, which can be raised or lowered as required. The flame of the gas passes between the small metal rollers, U, U, U, U, which are provided with an adjustment permitting the distance between each pair to be increased or diminished. The products of combustion, along with detached carbonaceous matters, are carried upwards into the hoods, K and K', which extend the whole width of the machine, whence they are drawn by the action of the fan, N, up the tubes and expelled into the external air. In the machine as shown the cloth is entering in the direction of the arrow over the scrimp bar, T, then passing under the roller, R, and over R_1 down to the metal roller, U'', where it first comes into contact with the gas flames; then passing over the rollers, R_2 and R_3, and down to the small metal roller, U''', it passes a second time, and on the same side, through the flame; then carried by the rollers, R_4 and R_5, down to the second pair of small metal rollers, it comes into contact with the flame of the second row of gas-burners, but exposing the reverse side of the piece to its action. By the rollers, R_6 and R_7, it is led again to the flame, and is a second time singed on the reverse side, and passing between the roller, H, which is kept wet by water in the trough, G, and the draw roller, E, it is taken by the wince, C, and laid down in folds by the plaiter arm, D. It will be seen by this system of threading that the cloth is singed twice on the face side and twice on the reverse side. The outline at *a* shows how the cloth can be threaded so as to be singed four times on one side, and in the arrangement *b* the cloth is singed twice only on one side.

Singeing by Flame and Plate Combined.—In 1862 a patent was granted to EDDLESTON and GLEDHILL for an apparatus to singe cloth by means of flame arising from burning coke or other combustible. The arrangement consists of a narrow furnace of fire-brick, open above, and so closed below that a blast from a fan or blower travels through the burning coke and produces a large flame above. The cloth to be singed is drawn over or through this flame by ordinary contrivances. When the furnace is in good condition and burning coke, a voluminous and smokeless flame is produced, which, when playing against the cloth, covers several feet of it at once. It would appear that this system of singeing was first intended for woollen goods, and when applied to cotton cloth was found deficient in power; but at this time it is used in conjunction with a copper-plate singeing furnace, and said to give good results—the cloth passing first over or through the coke flame, and then immediately over the red-hot plate. The passage through the flame evidently dries and warms the cloth, as well as singes off the longer hairs, and the single plate, working after the coke flame, can, it is said, be easily kept at a good singeing heat all the day; and thus the chief difficulty in singeing by the plate is avoided. Of course this is only another way of using gas, but probably the most economical way that could be devised; and when coke is the fuel employed, there can be no carburetted hydrogen in the gas, and consequently no smoke and no discolouring of the cloth by soot. For a drawing of the furnace, but not in conjunction with the singeing plate, see the patent, No. 197, January 25, 1862.

Of these three methods of singeing, it is difficult to say which is preferable. Gas is much cleanlier, and, on the whole, freer from danger of fire than the plate; but it is generally more expensive, and, as far as my experience goes, never so thorough or complete in its action. With TULPIN'S machine, and probably with other gas machines, a very fair singe can be got, and it is easily managed and pleasant to work with; but the writer had every opportunity of comparing it with goods singed by two plates, and preferred the latter. In EDDLESTON and GLEDHILL'S patent, whatever may be its merits practically, there seems no doubt that it is the plate which does the singeing, the flaming only preparing for and helping the plate. TULPIN'S machine, according to a paper by SCHULTZ (*Bull. de Mulh.* 37, 533), was tried at STEINBACH-KOECHLIN'S at Wesserling; 1000 mètres of calico required, in one trial, 1331 litres of gas, and in another, 1480 litres. In a trial near Manchester, 25,000 yards of calico were singed in seven hours, with a consumption of 1330 cubic feet of gas—the French experiment taking somewhat less gas than the English. At Wesserling the opinion was, that there was not much difference in the expense between gas and plate singeing; but that is a question depending upon the relative prices of gas and fuel. In other places the gas cost three times as much as the plate. In the plate-singeing, the wearing out of the plates is a large item of the expense. There is a great difference in copper plates: some wear away much quicker than others. One plate that I noted singed 2.400,000 yards of calico before it was taken out. With careless firing and with sulphurous coal plates are soon worn out. One pound of coal can singe from 80 to 120 yards of calico of narrow width.

General Remarks upon Singeing.—Whichever method of singeing be adopted, there are some general points to be attended to. While endeavouring to get as perfect a singe as possible, it is evident the cloth must not be burned or over-singed. Double edges are liable to be burned, on account, probably, of being pressed closer to the plate than the body of the cloth. If the plate is much worn in the middle, the two edges of the cloth are liable to be injured; and if the plate becomes much thinner in one part than another, that part will be much hotter than the rest. Fire must be carefully guarded against. Ends of threads, and knots from defective weaving, and ends of the sewing thread, are particularly liable to carry over sparks; and in dry singeing, as for back greys, some contrivance must be adopted to extinguish them. The best plan is to pass the goods through a box where a good jet of steam from a perforated pipe plays against the whole width of the piece, and keeps the box full of steam, and consequently cools down the piece; and by excluding atmospheric air, generally extinguishes all sparks. To secure this a strong current of steam is required: a feeble, low pressure is of little use. After making all allowances for the possibility of sparks, there are cases of goods firing which seem due to spontaneous combustion. If a spark is unextinguished, and carried over with hot cloth, it will cause fire in a few minutes; but there are cases where the fire has not developed itself until some hours after the goods were laid down. It is quite conceivable that some spot of grease or flour size, or other foreign matter on the cloth, is the origin of such a fire without any actual sparks being there. It should always be remembered that the calico after singeing is very hot and dry, and therefore liable to take fire from the smallest sparks. If there is a good ventilation in the singeing stove, and a hood to carry off the fumes and sparks, little danger can arise from floating sparks; but no one can be too careful of the very inflammable fluffy matter which collects about the brickwork, and some of which is occasionally carried on to the piece. In fact, dry-singed goods cannot be considered safe until they are cool; and wherever it is possible should be cooled by running over a series of rollers, or by being pulled over a rail.

Goods which go straight on to the bleachhouse are efficiently protected from fire by being made to pass through a trough of water, and between rollers which are lapped with some stuff which is kept saturated with water.

Good printer's cloth is now woven with very little size in it; but not very long ago managers were liable to be troubled with cloth containing 20 or 30 per cent. of flour size, and this is a great hindrance to singeing. It cakes upon the plate and cakes upon the cloth, and causes many stoppages and inconvenience, and in fact cannot be properly singed. In passing judgment upon the singeing, it must not be forgotten that some kinds of cloth have much more face on than others (a printer's cloth ought to have no face on), and are much more difficult to singe clean, and that cloth from low, short-stapled cottons, even if it be well singed, seems nearly as bad as ever after bleaching. This remark leads naturally to the question of why not singe after bleaching, instead of before? For the calico is knocked about a good deal in the process of bleaching, and many ends of hairs are loosened by the necessary movements of the cloth, undoing, as it were, what the singeing had done for it. The only reason is the discoloration of the white which would take place by the carbonaceous particles of the charred hairs adhering to the fabric; and though this discoloration is of a mere physical or mechanical pigment, it cannot be removed except by vigorous treatments, which would again leave the cloth as bad as before, or nearly so. But practically it is not unusual to singe after bleaching for particular styles where a slight discoloration of surface is of no consequence, as in dyed and soaped styles; or sometimes as in heavy dark blotches, the goods are singed after dyeing even, to remove the white hairs which, if left on, make this style so unsightly. But this after-singeing is additional to the first singeing, and should be done with gas or coke flame, so as to reduce the discoloration of the white to a minimum amount.

BLEACHING FOR CALICO PRINTING.—The next step after singeing is bleaching. This word means whitening, but in calico printing it has a wider signification; it means a thorough cleaning and purifying of the cloth from extraneous matters. It is an operation of the utmost importance: for with a well and soundly bleached cloth to work upon, all styles of printing may be attempted with hope of success; but against bad bleaching it is vain to contend. The best skill and the best materials are thrown away upon badly bleached cloth, and irregularity and inferiority will pervade every result. It is therefore a subject which demands all the attention and consideration which can be bestowed upon it.

The bleaching arrangement which is now almost exclusively employed is called "the continuous process;" the whole number of pieces of calico to be treated are sewn end to end, forming one or two unbroken lengths of cloth, which may extend from fifteen to forty miles, according to the quality and width of the calico and capacity of the kiers or boiling vessels. The ends of the pieces are not unsewn until the bleaching operations are quite finished, and this is all that is meant by the term continuous, for in practice the operations are intermittent, and the cloth is laid down and taken up many times in the course of the bleaching. The number and purposes of such movings of this long riband of calico are here shown in tabular arrangement, and each one may be considered as a distinct step in the bleaching, and naturally subdividing the subject into so many heads.

1. Wetting out and steeping of the calico in water.
2. First washing.
3. Liming and boiling with lime.
4. Washing out of the lime.
5. Souring or acid treatment after lime.
6. Washing out of the acid.
7. Boiling with soda ash and rosin.
8. Washing out of the soda-ash.
9. Treating with bleaching liquor or chloride of lime.
10. Souring after chloride of lime.
11. Final washing and drying.

Wetting out, *Steeping*, *Rot Steep*.—The first operation is to impregnate the goods thoroughly with water. This is usually done in conjunction with the singeing, and has for its chief object the softening and loosening of the starchy matters contained in the calico. Ordinary grey calico repels liquids so strongly, that a bit may be dipped in water and removed almost without being wetted. It may be observed, that if calico singed on one side is passed quickly through water, the singed side takes the water pretty well, while the other side is scarcely moistened. A second object in washing out is to prevent this temporary impermeability from producing irregularity in the liming, which would certainly take place if the grey cloth was passed into it without previous treatment. The older bleachers attached much importance to the steeping of the calico, which from the fermentation, or one might say putrefaction, which was set up in the mass, was generally called the rot steep. They believed that good results could not be obtained if the pieces were moved before a pretty active fermentation had taken place, and to insure this bran and other easily fermentiscible bodies were mixed with the water to promote the desired action.

They were probably right in their time, for they had to deal with a printer's cloth of a very different kind to that now supplied, and they had not the means of giving the effective subsequent treatments which were afterwards discovered. The displacement of hand-loom cloth, with all its abominations of domestic sizing, by the cleaner power-loom calico, and the gradual simplification of the sizing of this latter, combined with a more rapid transfer from the loom to the bleachhouse, have done much towards making bleaching easier and more certain than it was formerly.

At the present time an enlightened bleacher attaches no importance to fermentation, except to carefully avoid too much heating of the wetted cloth when circumstances have compelled him to leave it in a heap longer than necessary, and if it becomes heated, to cool it down either by moving it or by application of cold water. Grey calico, but slightly wetted, may become much injured from heating; if entirely submerged in water there is little or no fear of its becoming heated to a dangerous point. While there is an undoubted advantage in leaving the cloth several hours in steep, there is no absolute necessity for it; and if the routine of operations require it, the thoroughly wetted cloth may be at once passed on to the washing machine. Since it was discovered that diastase, which exists in a decoction of malt, had the property of rapidly transforming starch into soluble gum-like compounds, it has been proposed to use it in the steeping water; but even if effective, it is expensive and unnecessary.

First Washing.—The object of this washing is to remove whatever is soluble in water, or can be detached by agitation in it. These matters are mainly the weaver's size or a portion of it, and the salts which may have been added to it, as acetate of lead, sulphate of copper, with glycerine, and probably soap, and the soluble saline constituents of the cotton proper, which are very small in amount. The washing is not pushed far, for no practical time or quantity of cold water would remove all these matters; the bleacher is content just to take off what comes away easily, and what might form an obstruction to the liming. Whatever washing machine may be employed, it is advisable to give the cloth a good squeeze as it leaves it, so that as little water as possible may remain in; for well squeezed cloth, or if squeezing is not practicable, well drained cloth, is easier to lime than very wet cloth.

Application of the Lime to the Cloth.—Lime is nearly insoluble in water. The milky fluid called milk of lime consists of particles of hydrate of lime mechanically suspended in lime water. If the milk of lime is left at rest, these particles soon subside and leave a clear liquid, which contains but a small quantity of lime—not more than one part in weight to 700 parts of water: a fluid far too weak for bleaching purposes. That a sufficient quantity of lime may be applied to the cloth, it has to be used in the milky state, and care must be taken that it is applied with tolerable uniformity to the mass of cloth to be bleached. Formerly the lime was thrown on the cloth as it was deposited in the boiling kier by buckets or scoops, or run in by a spout. An improvement was to play the milk of lime upon the cloth with a hose pipe and nozzle; but these plans were defective, on account of the irregular and unequal distribution of the lime: some parts got an excess and some too little. A uniform impregnation is easily obtained by means of the modern liming machine, the cloth passing through a box or cistern of milk of lime on its way to the kiers, and the excess being squeezed out by pressure-rollers. It is well to have the lime slacked some time before it is wanted, to insure the perfect absorption of the water by the lime, and the absence of any bits of unslacked lime. Lime slacked to the consistence of a paste that can be taken up with a spade will keep good for a long time, if it is in pits where it will not dry, and is not much exposed to the air. In this state it is well adapted for bleaching. But it is not always convenient to connect such places with a bleachhouse; and lime will not run through small pipes, nor can it be pumped satisfactorily; therefore the slacking is generally done in the bleachhouse or close to it, so that the milk of lime can run to the liming machine through a spout or culvert by its own gravity. But still there should be no difficulty here in having a reserve, so that the lime for a boiling should be slacked at least twelve hours before it is wanted.

During the liming the milk of lime must be kept in constant agitation, or its strength will vary very materially. This can be done by hand, or preferably by a mechanical stirrer. If the lime is of a quality that slacks well—that is, fine and soft—it may be nearly all used up, except the stones and unburnt pieces; but there are some kinds of lime which give a large portion of a heavy, granular hydrate, causing much waste; for it is no use stirring the lime so violently as to bring up these heavy particles: they either settle in the trough or at the bottom of the liming box, and do not get on the cloth at all, or if the cloth takes them up, it is in an irregular manner. A good milk of lime has a translucent appearance in thin layers by reflected light, as, for example, when seen running down a trough into the machine. An opaque, starchy-looking milk of lime is to be feared as weak and inactive.

The length of time which the cloth is in contact with the milk of lime in the machine must depend on circumstances. A great deal of bad bleaching has been owing to insufficient liming, from want of time in the lime. At first it was thought that simply going down into a box about 3 feet deep, up again, and through the squeezers, was sufficient; then an additional box, with three or four rollers, was put before the squeezers; but experience has shown that cloth of average quality does not get lime enough unless it has two or three nips at least, and as many passages through the box, before the last squeeze. In fact, the cloth cannot be too long in the milk of lime; and if the bleacher can spare a washing machine for liming, his work will be all the better; for it must be considered that the cloth going into the lime is saturated with water. It has no desire to take up any more; and all that can be expected is that the milk of lime will displace a portion of the water already in the piece, and take its place. This cannot be done instantly, and cannot be well done in any time that can practically be allowed without the assistance of two or three squeezes of the cloth.

Amount of Lime to be Used.—Lime was at first used with great timidity by bleachers, at temperatures far below boiling, and the proportion to the cloth relatively very small. We find indicated in earlier recipes, 1 lb. of lime to 150 of cloth, then 1 to 50, and later, 1 lb. to 35 of cloth; increasing up to 1 lb. of lime to 15 of cloth, which is perhaps the largest proportion which can be profitably employed. Bleachers differ so much in their practice in this respect, that there cannot be said to be any precise rule; but as lime is cheap, and an excess is not injurious, there are no inducements to keep to a minimum quantity. Whatever be the quantity of lime employed for a boiling—suppose 600 lbs. for 10 000 lbs. of cloth—it is clear that to insure success it must be as evenly as possible divided amongst the cloth. This is secured by keeping the milk of lime in a box at a regulated strength. For practical purposes, the indications of the hydrometer are sufficiently close when observed with some degree of skill. Although this instrument is only intended for showing the specific gravity of actual solutions, it can be profitably employed in several cases of mixtures of suspended matters; but the result must be read off quickly, before the insoluble matters settle down. Though the distribution of the lime over the cloth can be regulated from the box, the only proper way of testing the strength of lime that is going into the kier is by wringing the fluid out of the cloth as this latter is being deposited in the kier.

The use of dilute acids will be found safer as a method of testing and controlling the milk of lime than the hydrometer—commercial muriatic acid reduced to say two degrees of Twaddle, and strongly tinged with litmus; logwood or cochineal answers very well. A stock of this should be kept, and all that is required is a phial marked with a file, at say half or quarter oz. distances from the bottom. Some of the lime liquor either from the box, or wrung out of the piece after leaving the box, is caught in the phial, and a given mark is reached; then the dilute acid is added by degrees, with shaking until the colour shows that the lime is neutralized, and the quantity required will indicate the strength of the lime. The absolute strength of the acid is not important; what the bleacher requires to know is, whether the cloth is getting regularly limed or not with the proportion of lime which experience has shown him to be the best. In a given case, the milk of lime in the box was at 5° Twaddle, and it required rather less than 2 oz. of the muriatic acid at 2° to neutralize 1 oz. of it; the liquor wrung out of the cloth as it was going into the kiers marked about 2° Twaddle, and 3 oz. of it were neutralized by 2 oz. of the acid.

Now it is evident that it requires some care to keep up this or any other ratio between the liquor in the box, and the liquor actually carried away by the cloth, for it is liable to vary on account of the different quantities of water carried into the box by the wet cloth, and by the amount of set upon the pressure rollers. For the latter half of a boiling the lime in the box must be stronger than for the first half; and all through the squeezer rollers must be set so as to allow the cloth to come through tolerably full of liquor, and so wet that a slight wringing causes it to yield the limy liquid in abundance, but not so wet as to cause the draw winces to splash it about the bleachhouse.

Boiling with the Lime.—The cloth thus uniformly impregnated with milk of lime is led directly from the liming machine into the boiling vessels, commonly called kiers. Great care is taken to arrange and pack the cloth with regularity; boys lay the long riband of calico at the bottom of the kier, by means of sticks, and tread down the cloth with their feet until the kier is filled, and it is then run up full with water. The next step varies according to the kind of kier in use; but whichever of the many systems of boiling described further on may be employed, the object is to submit every portion of the cloth to a long-continued boiling heat. The time of heating varies from nine to eighteen hours, and even longer, according to the construction of the kier, the pressure capable of being applied, and the quantity and quality of cloth operated upon. If the boiling in lime has been successfully carried out, a sufficient amount of lime used, and well distributed over the cloth, the heating sufficient and regular, and the cloth well laid down in the kier, the most difficult part of the bleaching has been overcome; the cloth, to use a bleacher's phrase, has been well bottomed, and the subsequent operations rendered easy and certain. If, on the other hand, from neglect of any of these conditions of success, the lime boil has not been effective, the after processes cannot correct the error, and if the cloth goes on it will turn out bad. If it is known that something has interfered to prevent full justice from being done to the boil, it is better to lime and boil over again than to try anything else.

When the boiling is completed, it is usual to run the hot liquid off, and fill up the kier with cold water, for it is thought that injury may result to the cloth if left in contact with the heated kier and the lime liquor. Whether this be so or not, it is well to cool the pieces, and then they may be safely left until it is convenient to wash them, for it does not appear that there is any danger of iron rust from the lime kier; however, the bleacher will get them washed as soon as he can, so as to be on the safe side.

Washing after Liming.—The pieces are passed through an ordinary washing machine to remove the excess of lime and other removable matters; the cloth may be considered sufficiently washed when the water wrung from it is clear, or it may be tested more exactly by red litmus paper, which changes to blue on contact with lime.

Souring after Lime.—The next step is to treat the cloth with a dilute acid. The term "sour" for weak acids, and "souring" for the process of treating cloth with these acids, come to us from the old linen bleaching process, in which the linen was steeped for four or five days in the sour fluids resulting from fermentation of bran or rye meal, or from sour milk, or what was thought best of all, butter milk. Dr. HOME, who paid much attention to linen bleaching in the middle of the last century, has many curious particulars about the souring process, which he considered was principally called for to remove earths, into which a portion of the alkali was changed by continual waterings and dryings of the cloth. Though wrong in this point, he had the sagacity to observe that the mineral acids, especially sulphuric, were quite as effective and much cheaper and cleaner than the sour vegetable and animal liquids then in use. He used "oil of vitriol in the proportion of half an ounce, or at most three quarters," to a gallon of water, and found the cloth was better with four hours' treatment of these sours than with five days of the old sours; he proved also satisfactorily that vitriol sours, properly used, had no injurious action upon linen; and from this time, and from his recommendations, may be dated the displacement of the old sours. The sours now used are made by mixing either sulphuric acid or muriatic acid with water, and they are applied to the cloth at a strength of from 1° to 2° of TWADDLE'S hydrometer. As the strong acids are destructive to the cloth, care must be taken that the mixture is properly made; and though it may seem superfluous to say that the strong acid and water should be well stirred together in the mixing cistern, yet serious damage has been known to arise from a neglect of this simple operation.

The mixed acid and water, at a strength double or treble of that required for actual application, may be kept in stone or lead-lined cisterns, from which leaden pipes with gutta-percha stop-cocks communicate with the souring box or souring cisterns. The most modern method of souring is by running the cloth through a machine similar to the liming machine. The pieces pass four or six times into and out of the sours, then between compressing rollers, and are then piled upon a stillage or laid down in a box for three or four hours. The older plan was to steep the cloth in the sours in stone cisterns, and by a pump bring up the liquid from the bottom and distribute it over the pieces. This system was perfectly effective if the cloth was well packed, so that none of it escaped the action of the acid; and the sours could be used for several successive lots of cloth by strengthening up until they got too dirty to be used. The souring machine is, however, an improvement, for the cloth is sure to be uniformly soured if the strength in the box is kept up. There may be a failure in this point if the hydrometer alone is trusted to, because a good deal of lime and other matters come off the cloth, and the liquid may mark 3° or 4° when there is not half a degree of effective acid in it. A solution of caustic soda tinted with litmus or cochineal may be advantageously employed to control the strength of the acid. Caustic soda, about or rather less than 3° Tw., will neutralize an equal bulk of sulphuric acid sours at about 2° Tw. A stock of this may be kept in the bleachhouse, and a small narrow phial, marked with a file at a capacity of 1 oz. from the bottom, and higher up at another ounce, is all the apparatus required. To test the sours the bleacher fills up to the 1 oz. mark with the sours, and then adds the coloured soda until the colour ceases to be changed. Of course the more soda it takes the stronger the sours, and the less the weaker. A skilful bleacher will run his sours rather stronger for the last half of a batch, both because the cloth is wetter as it enters the sours, it loses some sours by draining in the heap, while the lower part of the soured heap gets the drainings, and also because it has the least time in the sour. Of the two acids used for sours there is no doubt that muriatic acid is preferable in a chemical point of view; the compound it forms with lime is extremely soluble, and it has for the same strength a keener action upon insoluble oxides, such as iron and copper, than any other acid. Sulphuric acid is, however, generally used for economical reasons, and it does not in practice present the disadvantages which from theoretical grounds might be predicated. The amount of sulphate of lime formed on the cloth is not considerable; and though it is but sparingly soluble in cold water, it has nearly no attraction for the fibre, and is easily washed off. Souring after lime is not to be looked upon as of absolute necessity, but all bleachers are agreed that it is a very useful step, and contributes powerfully to the regularity of the process. If it is omitted a great deal of dirty stuff goes into the next boil; this could be in great part removed by extra washing instead of souring, but the cost of acid is so trifling, and the additional security so great, that a departure from this process is not to be recommended either on grounds of economy or despatch.

Washing after Souring.—This is performed in the ordinary machine, and is simply to remove the acid and all other matters rendered soluble or non-adherent by its action. Of course no sours should be left in the cloth, as they would neutralize the alkali in the following boil, precipitate rosin upon the cloth, and give rise to iron stains by contact with the kier sides before the alkali was run in; and some of these effects are liable to take place if even a very small quantity, inappreciable to the taste, remains in the calico. The cloth should be tested with blue litmus paper.

Boiling with Soda-ash and Rosin.—The quantity of soda-ash to be employed will vary, according to the quality of the water and the kind of cloth, from 1 to 3 per cent. of the weight of calico—3 cwts. to 10,000 lbs. of cloth being about the maximum proportion. There are two ways of applying the rosin; the first, to dissolve the crude rosin in the soda-ash just before using; and the second, to dissolve in the solution of soda-ash a previously prepared rosin soap. If the bleacher uses crude rosin the proceeding is as follows:—The requisite quantity of soda-ash is dissolved in an iron cistern, which is provided with a steam-pipe, and which should be placed so high above the kiers that the contents can be run into them by gravitation. The liquid is heated to boiling, and the scum which rises to the top, consisting chiefly of the earthy salts of the water, is removed, and the rosin, broken up, is added. The boiling is continued with stirring until the rosin has been completely dissolved and no particle is visible; this requires several hours; if necessary, the liquid is skimmed again to remove insoluble matters, which if carried on to the cloth might give rise to stains. The quantity of rosin used may amount to one half the weight of the soda-ash, and it is not advisable to exceed that proportion, though any quantity less may be used.

If prepared rosin or rosin soap be employed, the required quantity is simply mixed with the warm solution of soda-ash, and dissolved by heating and stirring, which take very little time. In this case the proportion of soda-ash is reduced by the amount represented by the alkali in the rosin soap. When the solution of rosin and alkali is prepared it is run upon the cloth, which has been previously closely packed in the kier, and the boiling is proceeded with and carried on for from eight to sixteen hours, according to the quantity of cloth or kind of kier used. When the boiling is terminated, the spent liquid is run off and the cloth washed as soon as possible to avoid iron stains, which are readily formed if the cloth in this state lies for a length of time in contact with the sides of the kier. If the cloth cannot be taken out and washed within a reasonably short time, it is well to leave the liquor in it, and not run off until shortly before it can be moved. The conditions necessary for success in this part of the bleaching process are sufficiency of alkali, and, of course, a proper boiling.

Washing out of the Soda-ash.—A single passage through the washing machine should be sufficient to remove all soluble matters; it is important, however, that the cloth should be well washed, and free from rosin especially; for the after processes will have no power to remove it, but rather tend to fix it.

Treatment with Chloride of Lime or Bleaching Liquor.—Dry bleaching powder is best dissolved by first making a thick cream of it with lukewarm water, and beating it well together to secure its uniform wetting; for it is rather repellent of water, and if not well mixed at first, small balls form, which are dry in the interior, and interfere with the settling and clearing of the solution. (There is a machine for mixing in use upon the Continent). It may be made to mark from 6° to 8° of TWADDLE's hydrometer, and should form a clear limpid solution, which generally has a sea-green colour in deep vessels. Formerly the goods were treated with the bleaching liquor in large stone cisterns, but in the modern continuous system of bleaching it is applied by a machine similar to that used for liming and souring. The chemicking machine, as it is usually called in Lancashire, is connected with the reservoir of bleaching liquor by leaden pipes, and a sufficient quantity is allowed to run in and mix with the water in the box of the machine, and the strength is kept up by a continual addition of strong liquor. The strength of the solution in the box will vary according to the work from ½° to 1° of TWADDLE's hydrometer, and whatever strength may be decided upon by the bleacher should be carefully maintained for the whole quantity of cloth, due allowance being made for the latter portion of a pile, which coming into the machine wetter than the earlier portion, and remaining less time under its action, requires the bleaching liquor to be a shade stronger. The hydrometer is not a trustworthy guide for dilute solutions; practical men are often guided by their sense of taste, but it is far better to adopt one of the plans of testing given further on, which may be trusted to give exact results. The cloth is left with the bleaching liquor in it for two, three, or four hours, and is then soured; or if time permits it is washed before souring, by which the unchanged chloride of lime is in great part removed, to the great convenience of the hands employed in souring.

Souring after Chloride of Lime.—This souring is conducted in the same manner as the souring after lime; but as, in nearly all cases, there is liberation of chlorine gas, the souring machine should be provided with a hopper and tube to carry the greater portion of it away. The soured goods themselves will sometimes smell so strongly as to seriously inconvenience the boys engaged in laying them down. There can be no doubt that, in such a case, there has been too much bleaching liquor used, probably to cover a fault in one of the boilings; or else the cloth has not lain long enough in the bleaching liquor before souring. This last souring is important, and must be carefully attended to; the strength of the sours must be kept up, so that no part of the cloth is undersoured; and it is clear that the other extreme of oversouring must be carefully avoided, or there will be difficulty in washing the sours out. The sours both in the box of the souring machine, and as they are expelled by wringing the cloth, should be tested at frequent intervals by the alkaline test liquor. A strength of 1° to 2° TWADDLE in the box, and of 1° to 1½° in the cloth, is about right for regular printing cloth. The cloth is left with the sours in for not less than an hour, and longer if convenient.

Final Washing out of Sours.—All that is required in this washing is that there shall not remain any trace of the sours in the cloth; and the bleacher ought to ascertain from time to time that this is the case by testing the cloth with blue litmus paper; and if there is the least uncertainty about it, the cloth should be rewashed. With a good supply of water, and ordinary care that the cloth is not too tight, one passage in the washing machine is sufficient. The calico now only requires squeezing and drying. The squeezers should have a water box fitted up in front, say 3 feet long, and furnished with rollers above and below, so that the cloth may have the advantage of a final rinse before it goes to the drying machine. Warm water is sometimes used in this box, and warm condensed water has been recommended as softening the cloth. If the condensed water is free from grease and iron, no doubt it is a good thing; but experience shows it to be a risky refinement, on account of probable impurities from the boiler or pipes.

High and Low Pressure Bleaching and Working of Kiers.—Although there are sufficient indications that high pressure, or the employment of temperatures higher than could be obtained by boiling in open vessels, was aimed at and actually used by CHAPTAL and others in the last century, the process was not put into a practical form until about twenty years ago by PENDLEBURY and BARLOW. Up to that time boiling was all done by low pressure steam, and the kiers were either quite uncovered or only lightly closed. At the present time the high pressure system is preferred, as being more rapid and economical, and its use is spreading; but there are still many and important works where the low pressure kiers are in use, and where the souring and chloring are performed in sunk boxes or pits. In point of quality there is no difference. One system of bleaching is as good as the other; and the low pressure bleachers express their belief that the cloth is less harassed, and not less perfectly bottomed, by their system than by high pressure. The frightful accidents which have resulted from the explosion of high pressure kiers had the effect of causing managers for a time to reduce the working pressure from 50 lbs. per square inch to 30 or 35 lbs. The writer has no hesitation in saying, that if the kiers must not be worked at any greater pressure than 30 lbs., there is no great advantage in having high pressure arrangements. At 50 lbs. the boilings may be effected in about two-thirds of the time, or even in one-half of the time, necessary for low pressure boiling, and this chiefly owing to the greater rapidity with which the mass of cold wet calico can be heated to the boiling point by the forcing of the hot fluids and steam through it; whereas in the low pressure kiers the steam is turned on several hours before the mere gravitation of the heated liquid falling from the throw-up pipe causes it to effectually percolate and influence the bulk of the cloth.

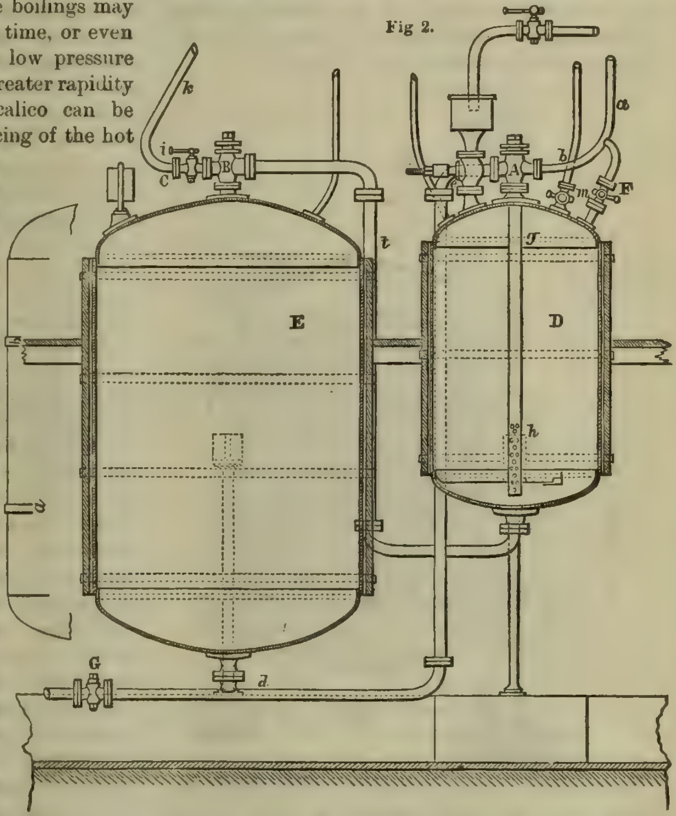


Fig 2.

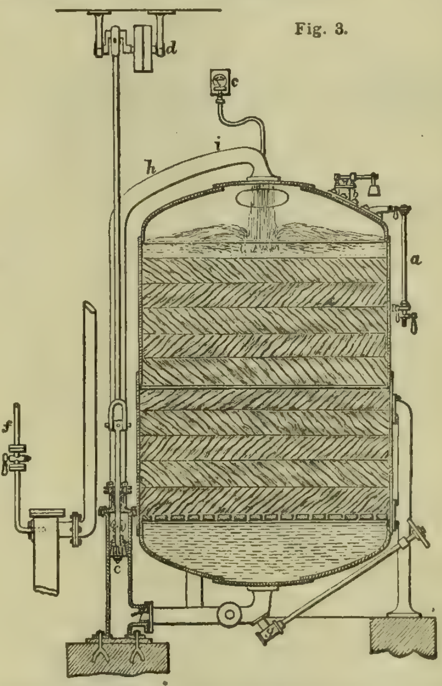
Fig. 2 shows one modification of Pendlebury's high pressure system; the cut and description of the method of working are taken from an excellent paper of M. Emile Burnat, in the thirty-eighth volume of the *Bulletin de la Société Industrielle de Mulhouse*, which shows the method of working at the great calico printing works of Dollfus-Miegs. The cloth kier, E, is about 13 feet high and $6\frac{1}{2}$ feet in diameter, and will hold about 8000 lbs. weight of calico. The liquor kier, D, is about $8\frac{1}{2}$ feet high and about $4\frac{3}{4}$ feet in diameter, and holds from 900 to 1000 gals. of liquid. The cloth is "entered" and the man-holes secured, and it was the custom to commence by blowing steam through the cloth until it escaped at G. This took twenty minutes, and the pressure on the upper part of the kier indicated from 20 to 30 lbs. The object of this blowing through was to heat the cloth and expel air; but it has led to frequent accidents in tossing about the cloth, and it is now usually dispensed with. The liquor kier, D, filled with water and soda up to *g*, is now heated by the steam from A, which passes to the bottom of the kier through the pipe *h*; the liquor is then forced into the cloth by shutting the tap A, and opening the taps F and B. This is a departure from the original method of working which was found advantageous. It takes about twenty minutes to pass the liquid over the first time, and then the pressure in E will be found about 52 lbs., and the pressure in D about 60 lbs. The valve, F, is now closed, and C and B are opened, so as to raise the pressure in E somewhat higher than in D (it is sometimes necessary to open the waste-pipe, *m*, to relieve D, but not usually). When this is accomplished, B and C are shut, and A is opened, the effect of which is to put E into connection with D by means of the pipe, *de*, going from the bottom of E. The liquid being cooled by the cloth in E, enters D slowly at first, but condensing, the steam forms a vacuum which speedily draws the whole liquid contents of E over. The liquor is again heated by steam coming through A; and when the pressure is up, it is driven over into E by a repetition of the first process, and so on until the cloth gets so hot that the liquor coming into D does not form any suitable rarefaction; and then the tap F is not further used, but the whole managed by the three-way tap, A. An expert workman can drive the liquor in and out of D six times in an hour. When the boiling has been sufficiently protracted, the let-off tap G is opened, and the liquor driven out; the man-hole covers removed, and the cloth taken out as soon as it is cool enough to handle.

Many varieties of kiers have been introduced, but none others than those mentioned have been largely used in practice. Attempts, more or less successful, have been made to work single kiers upon a circulating principle; some by naked fire, others by allowing a blow-off in the upper part of the kier, and others by employing pumps. Fig. 3 shows the arrangement of one of the latter class

It is a kier patented by M. Scheurer-Rott, of Thann. It requires no explanation but to state that the liquor is heated by the steam from *f* as it passes from the pump, *e*, by means of *h i*, to the top of the kier. *a* is the water gauge, *b* a safety valve,*c* a pressure gauge, *d* the pump crank, and *g* the let-off tap. It is said that this kier works well with soda, but that with lime the top pieces become tender.

In Barlow's kiers, when boiling with lime, a departure from the usual routine has been advantageously adopted. Both kiers are run up with water to a sufficient depth, and for a couple of hours the taps charged every five minutes, and then every twenty minutes to the end. This never leaves the cloth in the kier dry, and has proved in some places a remedy for stains of very uncertain origin. A drawing and description of Barlow's kiers is given in article Bleaching, pp. 372, 373.

Fig. 3.



Shearing.—The surface of the calico is not in a fit state for good printing as it is received from the bleachhouse; upon close inspection it will be seen that there are projecting knots and floating threads which could not be expected to be removed by the rapid and momentary process of singeing; there are also abundance of fibres, coarser than the hairs taken off by singeing, all of which together would be a hindrance in printing, accumulating in the colour box and giving rise to bad cleaning, or remaining on the cloth only to be detached or moved in the subsequent operations, and leaving unsightly white specks where there should be an even colour. Until lately these accidental obstructions were removed by drawing the whole calico, yard by yard, over a flat table, and cutting them off with sharp scissors by hand. About 1840 the shearing machine was introduced into calico printing; it is believed from America. A similar machine had been for a long time used in dressing woollen cloth, and but few changes were required to adapt it to calico. At first it was proposed as a complete substitute for singeing, but it was found that for high-class printing it was extremely defective, and it was some years before it found its proper place in the business. All the various makes of shearing machines are constructed upon the same principle; a shaft of the width of the piece carries a number of steel blades with serrated edges; these blades are fixed spirally on the shaft, and are ground to a very true cylindrical shape. This shaft is driven at high speed in close proximity to a stout steel "doctor" firmly fixed in the framing of the machine. The cloth is made to travel in a state of tension over the blunt edge of the doctor and between it and the rapidly revolving cutters; the doctor-blade is so set that the cutters just escape the true surface of the cloth, but intercept, cut, and remove all projecting matters. When the cutters are in good order they not only remove gross and bulky substances, like threads and knots, but a great deal of downy, fluffy matter, especially from calico made from short staple cotton; and it is certain that this fluffy stuff, if it were not taken off here, would make its appearance in the colour or on the lint-doctor of the printing machine.

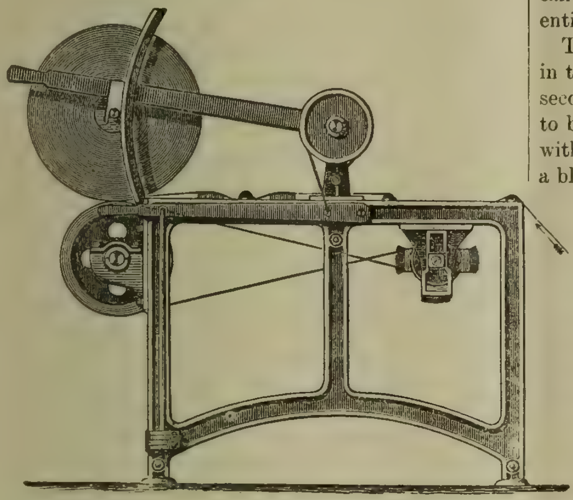
In shearing calico made from East Indian or other Asiatic cotton, so much matter is detached by the shearing that the atmosphere of the locality is filled with downy particles; and unless some effective system of ventilation exists by which they are removed, some portion settles down upon the cloth and gives trouble afterwards in the machine room. Those only who have been compelled to work where ventilation was impracticable, and the shearing machine placed near the printing, can understand all the difficulty arising from this circumstance. All good shearing machines are boxed in their lower part, and have receptacles to retain the matters cut off, but only a few have a connection with an exhaust fan, which at once removes all chance of injury from fluff.

Winding-on for Printing.—This is a simple process which is sometimes performed with the shearing, but is usually a separate operation, and is combined with a further cleansing of the cloth. The object is to wind the calico upon a roll for the printing machine. It should be done with an even and steady tension, and the selvedges carefully guided. The winding-on "canroy" is usually fitted with a circular brush to catch loose threads or other matters, and sometimes in foreign machines supplied with a set of beating rods, to shake dust out of the cloth.

Fig. 4 shows the most modern form of the canroy. The cloth enters on the right in the direction of the arrow; the roller with brushes revolves against the travelling cloth, which passes over stretching and scrimp bars, and is wound on a proper roller. The pressure upon the roller is regulated by the tension of a band passing in a circular groove of the arm fixed on the framework of the machine, the other end of which bears upon the metal axis of the roller or shell. A curved guide keeps the centres of the driving drum and roll of cloth perpendicular to one another.

Of the other treatments of cloth previous to printing little need be said, as they are exceptional. For fitting stripes another system of winding-on is required; for printing check patterns the cloth is better for being prepared in a stenting frame, by which it is made "square," that is, all the weft threads are made to take a position at right angles to the warp threads, as when they left the loom, but which in many cases is materially changed by the irregular and violent tension in modern bleaching processes. Those preparations of the cloth which consist in impregnating it with solutions of salts or mordants, are treated of either in connection with particular styles or in the section on mordants and prepares. The conditioning of calico for printing by mechanical means is difficult and impracticable for the most part. Cotton has so great an avidity for moisture that a very short time fits it for printing, even if it has been excessively over-dried; but it is very desirable that the "white room" should be in a cool locality, and that there should be always twenty-four hours' stock of cloth in it. It is far better for the cloth to be over-dry than the least moist, for in the latter case it takes off the plane parts of the roller that small trace of colour which is left on by the doctor, and the whites show it, to the great injury and even complete spoiling of the print in certain colours.

Fig. 4.



Application of the Design to the Calico.—It is probable that this was done at first by brush or pencil. It is recorded of the celebrated French house of Kœchlin Frères that, when they first commenced operations as calico printers (1746), all their goods were done by pencilling. The pencil, to fill in certain colours, was extensively employed both in France and England at the end of the last century in the best quality of prints; it was employed in England within the memory of living printers, but at the present time it is not used in any part of Europe; the name "pencil" remains attached to one colour, which could only be successfully applied by pencil, the orpiment solution of indigo, which both in French and English is called "pencil blue."

The use of blocks probably next followed; when introduced it is impossible to say. Mr. Merrifield concludes that blocks were not known in England at the date of the MSS. of Jehan de Begue, 1410, but it is probable their use in calico printing preceded their application in book printing.

In modern calico printing the block-printer fills a very subsidiary position; 99 per cent. of current prints are never touched by block, and of the remainder the block printer is only required to enter some colours which cannot be conveniently printed along with the main elements of the design. In some branches of woollen printing, and especially with heavy goods, as table-covers, carpets, and the like, all the printing is still done by block, and in some parts of the Continent, where labour is cheap and machinery dear, certain qualities of ordinary calico prints, in five or six colours, are worked entirely by block.

The apparatus of the block-printer consists first in the block upon which the design is cut in relief; secondly, of the sieve which contains the colour to be printed; and thirdly, of a strongly made table with a smooth surface of wood or stone covered with a blanket.

The block is variously made; for objects of moderate thickness and simple arrangement the design is cut upon some close and tough-grained wood like pear tree wood; for blotch or thick objects, the outline only is cut on the wood, and the inner part is hollowed out, and filled with fine cloth or felt called hatting. In order to prevent the warping of the block by successive wettings and dryings, it is backed by one or two layers of wood, fixed with the grain in a different direction, generally at right angles to the grain of the cut part. For finer lines or prints the wood is too fragile, and they are formed by copper wire flattened or drawn to the proper shape, and imbedded in the wood. Very elaborate and costly blocks are made entirely of such copper wire embedded in the wood. A more economical method of attaining the same end is by a modification of the stereotype process in letterpress printing; a mould is made by cutting or burning in a block of wood, and a fusible alloy run into it; this produces a casting, which is fixed upon a wooden block, and which being trimmed and smoothed, gives an accurate and durable printing surface.

The sieve, so called from its external resemblance to that article, is usually a round shallow wooden vessel, inside of which fits loosely a wooden hoop, covered with a waterproof cloth, and like a tambourine; the outer vessel or tub is partly filled with a pasty or gummy liquid, usually old or spoiled colour, and the waterproof tambourine swims on this pasty mass. A piece of fine woollen cloth free from nap is placed on the bottom of the tambourine, and the colour to be printed is spread by means of a brush on this cloth in an even and regular layer. The block with the cut part downwards is lightly pressed on this layer of colour; it takes up a portion, which is then transferred to the cloth to be printed.

It will easily be understood that a yielding, elastic surface, such as is obtained by this contrivance, is very suitable for imparting colour to all patterns of the block which stand in relief, and it is the invention of the sieve which enables very excellent effects to be produced by block-printing. The Chinese of this day are described as using blocks for printing calico, but not knowing or not using the sieve, their process is exceedingly slow and laborious.

All the contrivances to print more than one colour by one impression of the block, which have met with any success, are based upon modifications of the sieve. There are many methods of so arranging the sieve that one part of it shall be supplied with one colour, and another part with another colour, to the number of six or eight; and if the block is cut and guided to press only upon these parts, it takes up the colours without confusing or mixing them, and they can be transferred to the cloth. One of the most usual apparatus is generally known in the trade as the "Toby Tub." The sieve cloth in this case is of an open texture, and cemented to the borders of a series of canals cut in wood which supply the colours from beneath. These canals, of which there are as many as there are separate colours, are so led under the sieve cloth as to come to the surface in the proper places for the pattern cut on the block, and keep these places moist with the respective colours. The reservoir of colour is usually an inverted bottle acting as a fountain, and keeping the supply always at the same level at the heads of the canals. In "peg printing" with several colours at once, the colour is furnished to an ordinary sieve by means of a sort of rough block with projecting pegs; these pegs dip into vessels of colour, and furnish the sieve from which the block-printer supplies his block.

No fine printing can be done by any of these arrangements, and they are restricted to putting on solid objects mostly within boundages, and where exact outline is not necessary.

The block-printer's table requires little description; for regular work it is about 6 feet long, but for special purposes there are tables 30 feet or more in length, so that the whole of a piece can be put into position at once. The attempts which have been made to apply machinery to block-printing have not been productive of anything permanently useful to the trade of the garment printer. The machine which has been most widely employed is that called the "Perrotine," but though a few of these machines are still in work on the Continent, it is doubtful if one has been in use in Great Britain for many years past. The variety of block-printing called surface printing, and consisting of a number of blocks fixed upon a cylinder, and supplied with colour by an endless sieve cloth, has almost entirely disappeared from regular calico printing. The great advance which has been made in the art of engraving copper rollers has made it possible to produce effects by their means, which a few years ago could only be accomplished by block or surface roller.

Stencil plate printing was formerly practised, as is evidenced by ELLIOT'S patent in 1751, NICHOLSON'S patent, 1790, and others; the latest patent referring to this method of printing is to HENRY (communicated from DESPREAUX), 5th December, 1861; but it is only a very exceptional process.

ROLLER OR CYLINDER PRINTING.—The earliest description of a roller printing machine is contained in a patent to KEEN & PLATT, 10th March, 1743; it describes a machine for printing three colours, a separate bowl to each colour. A single roller printing machine was patented in 1772 by ATKIN; the printing roller was made of sycamore, and engraved to the depth of $\frac{1}{8}$ of an inch. It occupied the middle place between two other rollers, running in slots in upright oaken beams; the lower roller furnished the colour, and the upper roller acted as the bowl—how the roller was cleaned from excess of colour does not appear. The machine was driven by power applied to the projecting axis of the middle roller. Whether this and similar machines were ever practically used in the trade is uncertain, but it is clear that the idea of continuous printing from circular surfaces was abroad; and as at this date the engraving of flat copper plates, and printing from them, was carried to a high degree of perfection, the time was come for a radical change in the system of calico printing. The credit of inventing the printing machine, essentially as we have it now, is generally ascribed to THOMAS BELL,* whose first patent is dated 17th July, 1783. He figures and describes a cylinder machine for printing six colours at once. In all the first machines the rollers were arranged in a manner which seemed quite natural to the inventors, but very curious to modern printers—upon the upper part of the bowl or cylinder. In BELL'S second patent, 9th July, 1784, he describes a three-colour printing machine of the same general construction as the six-colour machine of the previous year. In these patents occur the first mention of "doctors" and "box-doctors" for furnishing colour, of scrimp rails, iron mandrills, and copper shells. In SLATER'S patent, 29th April, 1784, for a surface printing machine, lapping is first mentioned for the bowl and for the furnishing rollers; brush furnishers are also mentioned. In PAUL'S patent, 1796, there occurs the first mention of box wheels, mandrills with turned necks to work in steps, and made square in the body to prevent the turning inside the roller; also a traverse motion for the tearing brushes. It seems certain that BELL'S machine was applied at LIVESEY, HARGREAVES, & Co.'s works, near Preston, in the year 1785, and was really the first machine known to work satisfactorily. BELL may be considered the inventor of the printing machine in the same sense that WATT was the inventor of the steam engine. They each

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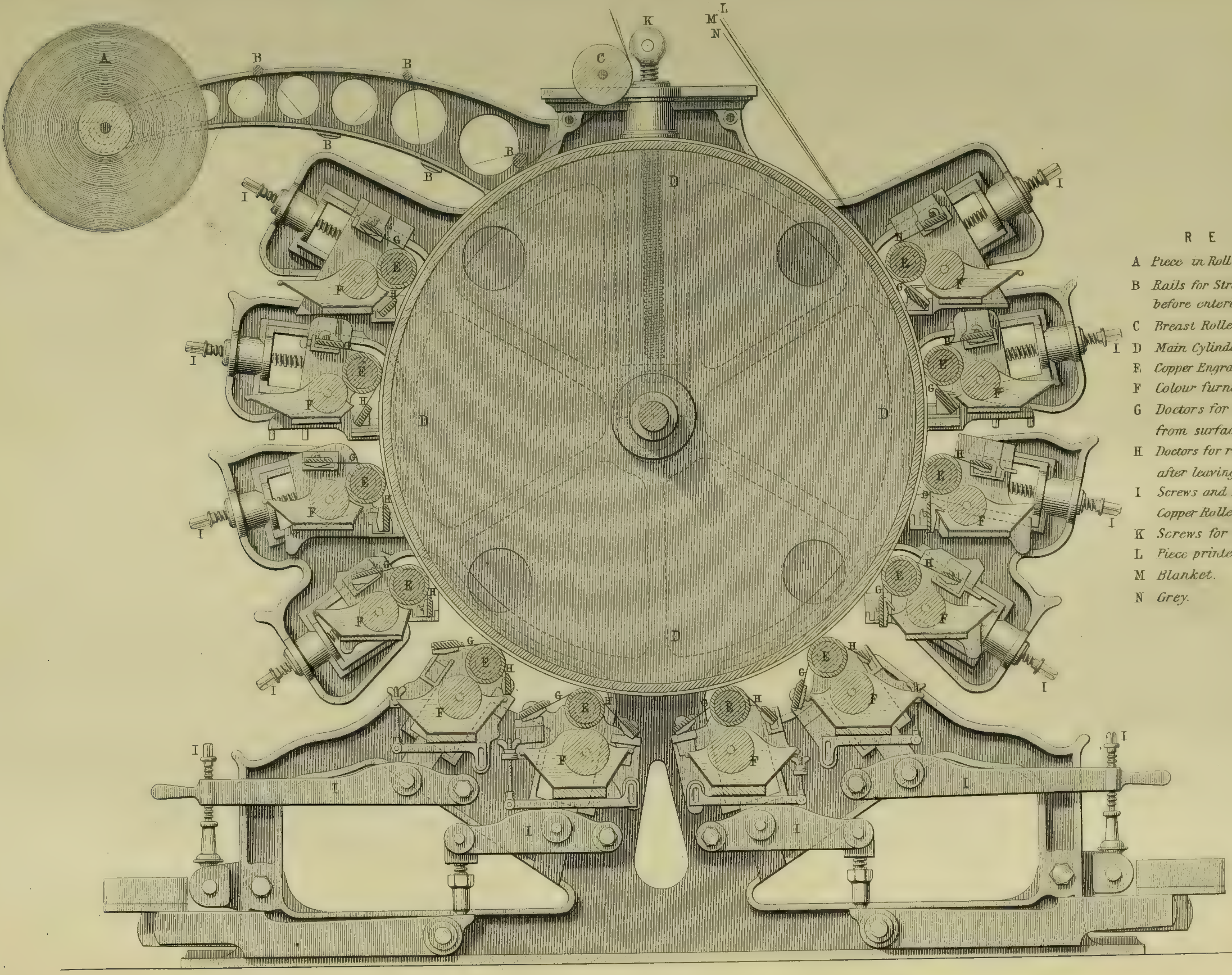
* The claims which were formerly made in favour of OBERKAMPF, a French printer of the last century, are now quite withdrawn by all respectable authorities; although it still continues, probably from oversight, to be inserted in late editions of GIRARDIN'S *Leçons de Chimie.*

CALICO PRINTING.

SECTIONAL ELEVATION OF TWELVE COLOUR MACHINE BY THOMAS GADD



REFERENCE.

A	Piece in Roll to be printed.
B	Rails for Stretching and Straightening same before entering Machine.
C	Breast Roller.
D	Main Cylinder of Machine.
E	Copper Engraved rollers with portions of Pattern
F	Colour furnishing Rollers and Boxes.
G	Doctors for removing superfluous colour from surface of Engraved Rollers.
H	Doctors for removing Lint adhering to Copper Roll after leaving colour upon cloth.
I	Screws and Levers for setting up engraved Copper Rollers and appendages.
K	Screws for regulating position of Main Cylind
L	Piece printed leaving Machine for drying.
M	Blanket.
N	Grey.

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found something before them, very clumsy and ineffective, and by their discoveries made it practical and efficient.

Plate I. shows the sectional elevation of a modern machine capable of printing designs of twelve colours, or any less number; the Plate shows it fitted with rollers and colour boxes for the whole twelve colours. The calico proceeding from A, in the white state, is delivered at L, imprinted by each of the twelve rollers with the portion of the design proper to each roller, and with the shade of colour required to obtain the effect intended. The necessary pressure for printing is obtained by means of screws and levers; and in the case of the former there is to each nut through which the screw passes a backing of stout india-rubber rings, which gives a certain amount of elasticity, and avoids the inconvenience which would result from irregularity in the thickness of the blanket acting upon a fixed unyielding pressure. The back grey is not seen entering the machine. At the exit the letters, M N, should be transposed, the back grey being next to the printed piece. The references engraved on the Plate will explain fully the other details of this machine.

Plate II. shows a printing machine for eight colours, by the same makers, in front view, and the method of driving it by an independent engine. Printing machines, especially when exceeding eight colours, are best driven by separate engines, on account of the control which the printer has over the speed at which it is desirable to print, and the ease and smoothness with which the machine can be stopped and started. But separate engines are of comparatively modern introduction in machine printing, and the greater number of machines are still driven by main-shaft and cogged gearing from the principal engine of the print works. By an arrangement of different sized cog-wheels and levers for connecting them with the shaft, the printer has command of three different speeds, slow, medium, and quick; but the starting of the machine and changing of the speeds while at work are accompanied by jerks and shocks of a disagreeable kind, often giving rise to accidents. Many attempts have been made to remedy this inconvenience by the adaptation of friction gearing, but it is believed that none of the systems in use answer in a satisfactory manner. The continental machines, which are not provided with separate engines, are for the most part driven by broad straps and pullies, and this would seem the best method of driving by friction, for though expensive, and requiring much attention, the starting, stopping, and driving are very smooth, and without shocks.

The waste or exhaust steam from the small engines can be utilized for heating the drying apparatus attached to the machine. The drying apparatus consists of a number of hollow cast-iron chests supported on an iron frame. They are heated by steam, and the printed piece is made to pass close to, but not in contact with, the heated metal. The speed of printing depends in a great measure upon the power of the drying chests, for it is an essential point that the colour shall be quite dried upon the cloth before it leaves the machine. To secure sufficient heating surface the steam chests are multiplied to the number of fifty or sixty, and the printed piece, as well as the blanket and back grey, led by means of rollers up and down among the heated chests, so as to utilize as much as possible of their heat.

Plate III. shows an elevation of a twenty-colour machine made by GADD of Manchester. It is the largest machine which has yet been constructed, and is now working at the Castleton Print Works, near Manchester. There are very few styles in which more than a dozen colours can be effectively combined; but this machine, as well as machines for sixteen colours, are regularly in use for printing elaborate furnitures and hangings, which imitate very well at a very low price the costly productions of block-printing. Although this machine has been called the largest machine yet made, this must be understood only of the number of colours which can be printed. There was a machine made some years ago by the same makers for printing only three colours, but as the printing rollers were to be each 5 feet in diameter, instead of 6 or 8 inches as in the usual machines, the framework and bowl would make it the largest printing machine in existence. It was believed to be applied to the printing of imitation Indian shawls. What success attended its application, or whether it is still at work, the writer has no knowledge.

Plates IV. and V. illustrate the most modern make of a French printing machine for printing eight colours, constructed by MM. TULPIN FRÈRES, of Rouen. Plate IV. gives a front view and shows the method of driving. The most noticeable feature in this is that the box-wheels, instead of being on the mandrills, are separated by shafts of 3 feet or so in length, which carry couplings to connect the mandrills. This construction is believed by continental makers to give a truer motion to the rollers and to require less power, diminishing or destroying, by means of the two bearings in the intermediate frame, the twist produced by the action of the cog wheels upon the roller in the usual English construction. Further, it will be seen that the main bowl is movable, and intended to be raised entirely away from the rollers by means of the fly wheel, F, acting upon the screw, H (Plate V.). This arrangement is not found in any English machines of modern construction. It apparently facilitates the labours of the printer when changing rollers and cleaning up; and when the machine is stopped for half an hour or so, without requiring to change rollers or colours, the bowl is raised and the rollers slowly driven, which perhaps may save some trouble at re-starting, by preventing the drying of the colour on the rollers. In Plate V. it will be seen that all the rollers have a lever pressure, most of them of a direct simple action; and further, that the printer is able to command the four rollers at the back of the machine without stirring from his place at the front. Other details are sufficiently explained by references on the Plates.

Such is the printing machine supplied at the present day to calico printers. Its construction varies in details as made by different houses, but not in any important particular; and now it remains to consider the appurtenances which are necessary for printing, and the application and management of which constitute the business of a practical machine printer.

Lapping.—The bowl is first to be lapped with several folds of cloth, in order to obtain a surface with a certain amount of compressibility and elasticity. The ordinary lapping is a strong and rather coarse tissue made with a woollen weft and linen warp. There are various qualities of it, differing in fineness according to the style of print required; but in all the qualities it should be made of very good materials, for it has not only to resist enormous pressure, but also a pulling and grinding motion which speedily destroys inferior materials. The first layer is made to adhere to the bowl with gum or paste, and the additional layers smoothly and tightly wrapped round; the ridge which would be left on the last round is softened and reduced by drawing out 2 or 3 inches of the weft threads, and laying the warp threads smoothly down on the previous layer. The thickness of lapping to be applied depends entirely upon the nature of the goods and kinds of colours to be printed, and is a practical detail to be left to the discretion of the printer.

Besides the ordinary lapping, there are lappings made of calico and other materials, coated on one side with solution of india-rubber and gutta percha; these have been very profitably applied in many places, but cannot be said to be in general use, on account of some practical difficulties connected with changes which take place in the india-rubber by pressure and heat.

It has been proposed to cover the bowl with a fixed layer of gutta percha, and endless sack lappings of elastic cloth have been made, which had to be slipped over the end of the bowl, requiring the side of the machine to be taken down; but these contrivances have only a limited application.

The Blanket.—This stands in the place of the table blanket of the block-printer. It is a fine, thick, strong woollen cloth, made from very good wool, and woven in lengths of 40 or 50 yards; it is of various widths and fineness, and may cost from 9*s.* to 12*s.* per yard; it is fitted on the machine so as to run endless, and the extremities are joined by careful drawing together with fine woollen or silk thread.

The Mackintosh blanket was introduced in 1840 by Leese. It consists of three or four layers of calico cemented together by solution of india-rubber. It is much employed in machine-printing, and preferred to the woollen blanket for some styles, especially for working with fine and therefore shallow engraving. It is not so soft as the woollen blanket, and is not so suitable for deep engravings, for printing massive objects, or generally when it is required to transfer as much colour as possible from the engraving to the cloth.

Blankets made entirely of cotton have also been introduced from America, but though said to be applied there with success and economy, have not found much favour in this country.

The blanket is the true printing surface, upon which the cloth rests when it is receiving the impression; but it is found highly convenient to interpose a piece of calico between the blanket and the piece to be printed. The principal reason for this is to preserve the very expensive blanket from being soiled by the colour, which often passes right through the printed piece, and also from the colour on the extreme ends of the roller, which cannot be always cleared off by the doctor. Unbleached calico is usually employed for this purpose, and the piece is generally known as the *back-grey*. The same pieces may be used two or three times, and are then sent to be bleached and afterwards printed as white calico.

Blankets can be entirely dispensed with by using two or three thicknesses of grey cloth; and many machines are fitted up with what is called grey tackle, by means of which the same length of grey cloth going from a roll is made to pass in a double or triple fold between the lapping and the white piece. This system, which promised to relieve printers from the expense of blankets, is not found, however, to be of such general application as was at first predicted, principally on account of the large stock of greys which would be required, and the inevitable though small damage to the greys themselves.

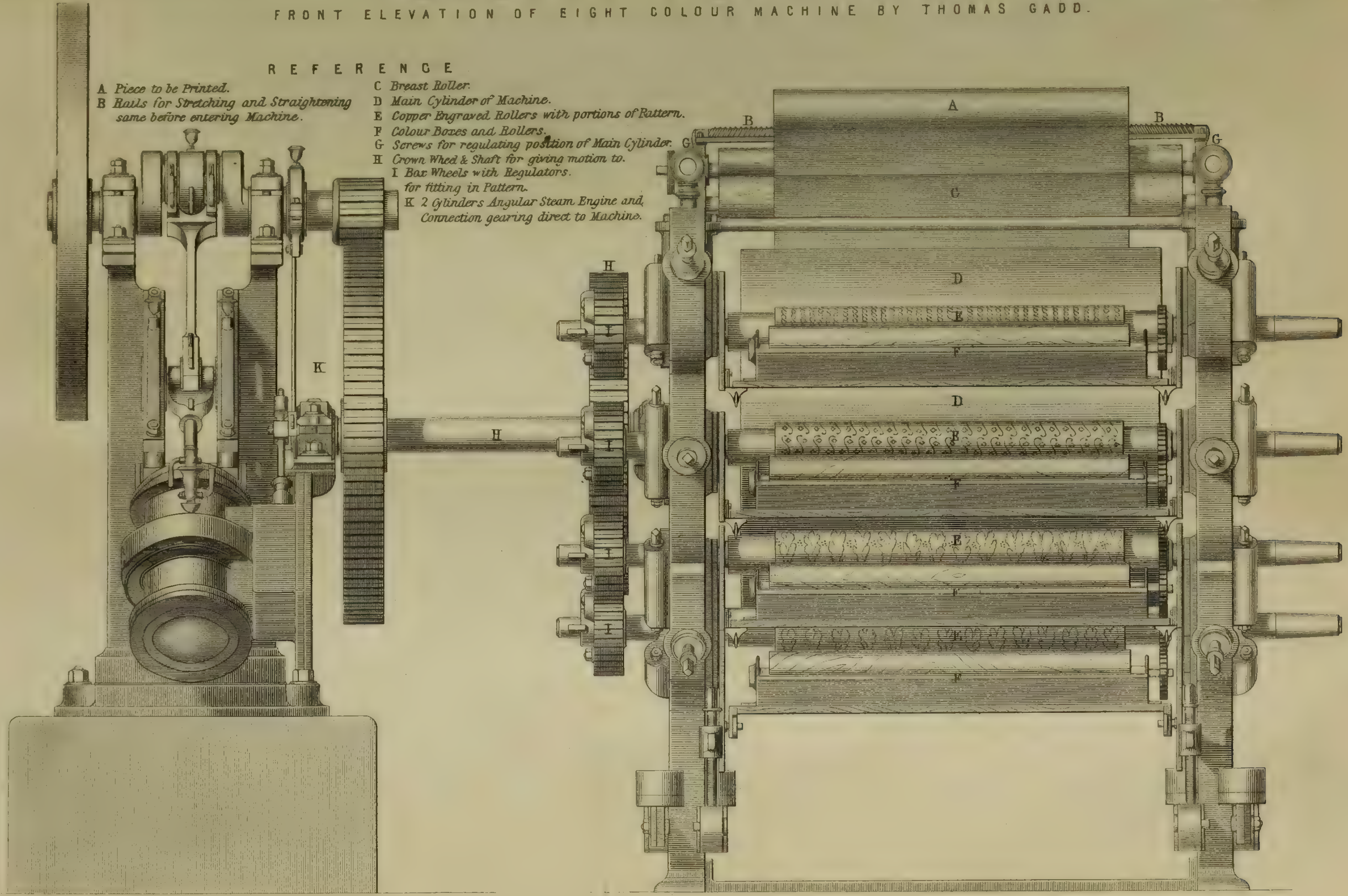
Washing of Blankets.—The blanket in course of working gets incrusted with colour near the edges, which must be removed from it at certain intervals, necessitating the running of the machines for two or three hours while it is washed and scraped, or else the taking the blanket out of the machine. To avoid this some machines are fitted up with blanket-washing apparatus, which is in continual action. Dalglish's method includes a squirt pipe, with brushes and a scraper; a revolving sponge serves to absorb the water. There are other methods similar; but the inconveniences attending the use of such apparatus is so great that they are of very limited application, and do not seem to be required, except in working many-coloured patterns in steam colours upon delaines or woollens, where the engraving is very strong, and much colour passes through the piece.

Mandrills and Rollers.—The mandrill is a shaft of wrought iron or steel made to fit the copper shell which bears the engraving. It is provided with a slot to fit a corresponding tab in the interior of the shell, so as to prevent any turning of the one inside the other. The ends of the mandrill are turned to fit the brass steps which carry it, and it is connected with the driving wheel of the machine by a complex cogged wheel called a box wheel, which fits on the end of the mandrill, and is secured on it by a cotter. The attempts which have been made to construct adjustable mandrills have not had much practical result; the parts have not sufficient strength to resist the usual rough treatment of a printing-room, and little change has been made in the mandrill from the

PLATE II.

CALICO PRINTING.

FRONT ELEVATION OF EIGHT COLOUR MACHINE BY THOMAS GADD.



REFERENCE

A Piece to be Printed.
B Rails for Stretching and Straightening same before entering Machine.
C Breast Roller.
D Main Cylinder of Machine.
E Copper Engraved Rollers with portions of Pattern.
F Colour Boxes and Rollers.
G Screws for regulating position of Main Cylinder.
H Crown Wheel & Shaft for giving motion to.
I Box Wheels with Regulators for fitting in Pattern.
K 2 Cylinders Angular Steam Engine and Connection gearing direct to Machine.

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commencement of cylinder printing. Steel mandrills are more rigid than wrought iron, and less liable to yield under the pressure brought to bear in printing; but they are, on the other hand, more brittle, and have been often seen to give way and break at the shoulder, near the step.

The copper roller, which is engraved with the design to be printed, is a hollow cylinder having a thickness of copper varying from 1½ inch to less than ½ inch. Engraved copper cylinders are mentioned in a patent granted to FRYER in 1764, twenty years previous to BELL's patent for the cylinder printing machine; but it is believed that all the copper cylinders used at that time, and long afterwards, were merely plates of copper bent round a mandrill, and the edges secured by soldering or brazing. The production of rollers from solid ingots of copper by drawing and boring seems to date from 1811, the process being described in FOTHERGILL's patent of that year. Many efforts have been made to make use of thin copper shells instead of the heavy and costly roller; but unless used with a permanent mandrill, and very well secured to that, they get speedily injured in working. Covering iron or cheap metals with a coating of copper, by electricity or other means, has also been attempted, but as yet without any practically useful results. Brass rollers are employed to a limited extent; but the metal is never so compact and homogeneous as copper, and presents difficulties both in engraving and printing.

Engraving.—The engraving of rollers is sometimes carried on in the print works, but more generally outside, by special engraving establishments. It is an art of itself, which, with copper roller making, is carried to the highest degree of excellence in Great Britain. In every print-works there should be means of repairing damaged engraving, polishing rollers, touching up defective parts, and deepening where the engraving has become too shallow. Only a brief and elementary account of the methods employed in engraving for calico printing can be attempted here.

Engraving by hand by burning is now extremely limited. It is only used in designs of very large sketch, such as for hangings, furniture, and shawls.

Mill engraving is employed for designs of small sketch—that is, where the same object or figure is repeated at short distances in the design. The figure to be engraved is cut by hand upon a small cylinder of softened steel. When completed, the metal is hardened, and an impression in relief is obtained from it upon another cylinder of soft steel by a very powerful rolling pressure. This cylinder being somewhat hardened, is the mill, and is used to produce the engraving upon the comparatively soft copper by pressure in a specially constructed machine, in which the roller to be engraved is made to receive the impression all over, or in certain parts only.

Engraving by etching with acids was practised at very distant periods for fine art purposes, but was not largely used for calico printing until after the discovery of the Pentagraph machine. The system of engraving by etching consists in covering the plain copper roller with a layer of bituminous varnish, capable of resisting for some time at least the action of strong nitric acid. The varnish is removed by a sharp pointed instrument in every place where the design requires it. The roller is then placed in a bath of nitric acid, which etches or eats into the bared metal to a depth sufficient to carry colour. It is then washed, the varnish removed, and with some little polishing is fit for the printer.

The Pentagraph is a machine for quickly and accurately moving the sharp points which cut the design through the varnish; and where diamond points are used, the surface of the copper itself is slightly abraded at the same time, and the commencement of the etching action very much facilitated. This most ingenious and valuable machine could not be described without detailed drawings. By it an unskilled hand, by causing a tracing point to follow an enlarged drawing of the design upon a metal plate, makes diamond points, varying from six to forty-eight in number, simultaneously to move and cut through the varnish on the roller in the most regular and exact manner, reproducing on a diminished scale the drawing traced over. It is only necessary further to mention that punches, ruling machines, and electrical deposition of copper, are also employed in producing engraved effects on rollers.

Doctors.—The doctor blade used for scraping the excess of colour from the roller is usually made of steel. It may be from a sixteenth to the twenty-fourth of an inch in thickness, 2 to 3 inches broad, and somewhat longer than the length of the roller. It is very uniform in thickness and in quality of metal, finely tempered enough to take a keen edge, but not so hard as to be difficult to cut with a good file. It is supported by being screwed, for all its length and ½ inch of its depth, between two plates of iron, usually called the doctor shears, which have bearings at the ends to fit in steps, and are also provided with means of connection with the traverse motion.

Composition doctors are made of brass, and are used for some colours which act rapidly upon steel. The so-called silver-nickel doctors are supposed to be still less easily acted upon than composition doctors. Neither of these can be tempered to so exact a degree as steel. They are always soft, do not wear well, and do not clean so reliably.

If there is one point more than another about a printing machine which tests the skill of the printer, it is shown in his knowledge of the management of the doctor. Well used, it produces clean work, full impressions, and preserves the engraving; unskilfully employed, the prints show streaks and smears, the impression is bare and uneven by the colour being dragged out of the engraving, and the engraving becomes so torn up and worn out as to be unfit to print in a very short time. The whetting of the doctor, the nature of the edge to be put on, the angle at which it is to be applied to the roller, the weight to be hung on the shears to keep it in contact with the roller, the thickness of the doctor blade, and other like points, are only to be learned by experience and observation, since they must vary for different styles of engraving, thickness of colour, and style of work.

The traverse motion of the doctor is obtained in various ways, and very important improvements have been made in it of late years. In the older machines the traverse was obtained from the blanket roller, and consisted in a simple backward and forward movement of a fixed and unchangeable range; in the modern machines the traverse is a very complicated movement, though obtained by simple means, and is so managed that any given points of the doctor and roller fall in the same line only at considerable intervals. The effect is, that the wearing of the doctor edge is made much more uniform, and the destructive action upon the engraving is reduced to a minimum amount.

Fitting of Patterns.—When designs of two or more colours are to be printed the question of fitting comes into consideration; that is, the placing and keeping the different rollers in positions so that the parts of the design fall accurately in their right places. Supposing the engraving to have been well done, the following are the principal means at the disposal of the printer for fitting. Marks called pitch-points are usually made near the ends of the rollers at first; the rollers to be fitted being placed in the machine, the printer roughly fixes them so that the mark made by the pitch-point on the first roller falls as near as may be on that made by the second roller, and so on for the remaining rollers; and then the box-wheels being fixed on and geared, the adjustment is completed by the box-wheel, which enables the printer to turn the roller and mandrill to a limited extent forward or backwards in relation to the direction in which the piece travels. To obtain a change of lateral position the steps carrying the mandrill are made movable, and by a screw the mandrill can be forced to the right or left as required, and a further range can be obtained by raising or dropping the steps, but good printers very rarely use this means, except to a very limited extent. Notwithstanding all the care and accuracy which are spent upon the machine, it is evident that the lapping, blanket, or even the bowl itself, and the driving wheels, can only be approximately true; and as in some close-fitting patterns a hair's-breadth out of truth spoils the work, the printer cannot leave his machine for a minute when it is printing, but with the screw-key in his hand watches closely the progress of the piece, and is incessantly moving about, backwarding this roller, forwarding the other, moving this slightly to the right and the other to the left, raising one end a little and dropping another, thus counteracting the inequalities and inevitable defects of the machine, blanket, and cloth. The engraver does all that is possible to make the fitting easy, and takes advantage of all the points in the design where any overlap can be allowed, or where one colour can fall without injury upon another; an allowance is made for the stretching and narrowing which the calico undergoes by the tension it is subjected to between the first and second rollers, and even beyond that. It is plain that the calico must enter the machine at a constant state of tightness; this is attended to by having it carefully wound on beams, and fed into the machine well stretched by means of scrimp rails and friction bars; and this duty occupies the whole time of an assistant, whose place being at the back of the machine, is generally called the back-tenter.

Colour Mixing for Printing.—The mechanical operations in the colour shop will vary in different places, but they may be said to consist in mixing, boiling, and straining the colours. It is not intended in this part to enter into details of particular colours, but in addition to the routine practical operations, it will be necessary to study the general character of thickeners, vehicles, and mordants.

Fig. 5.

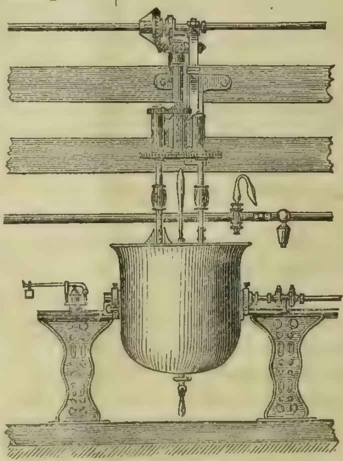
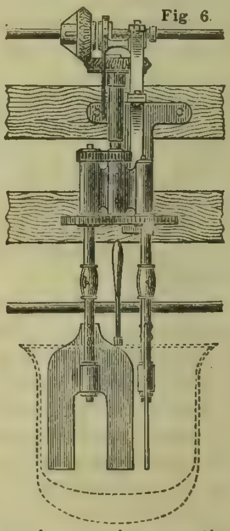


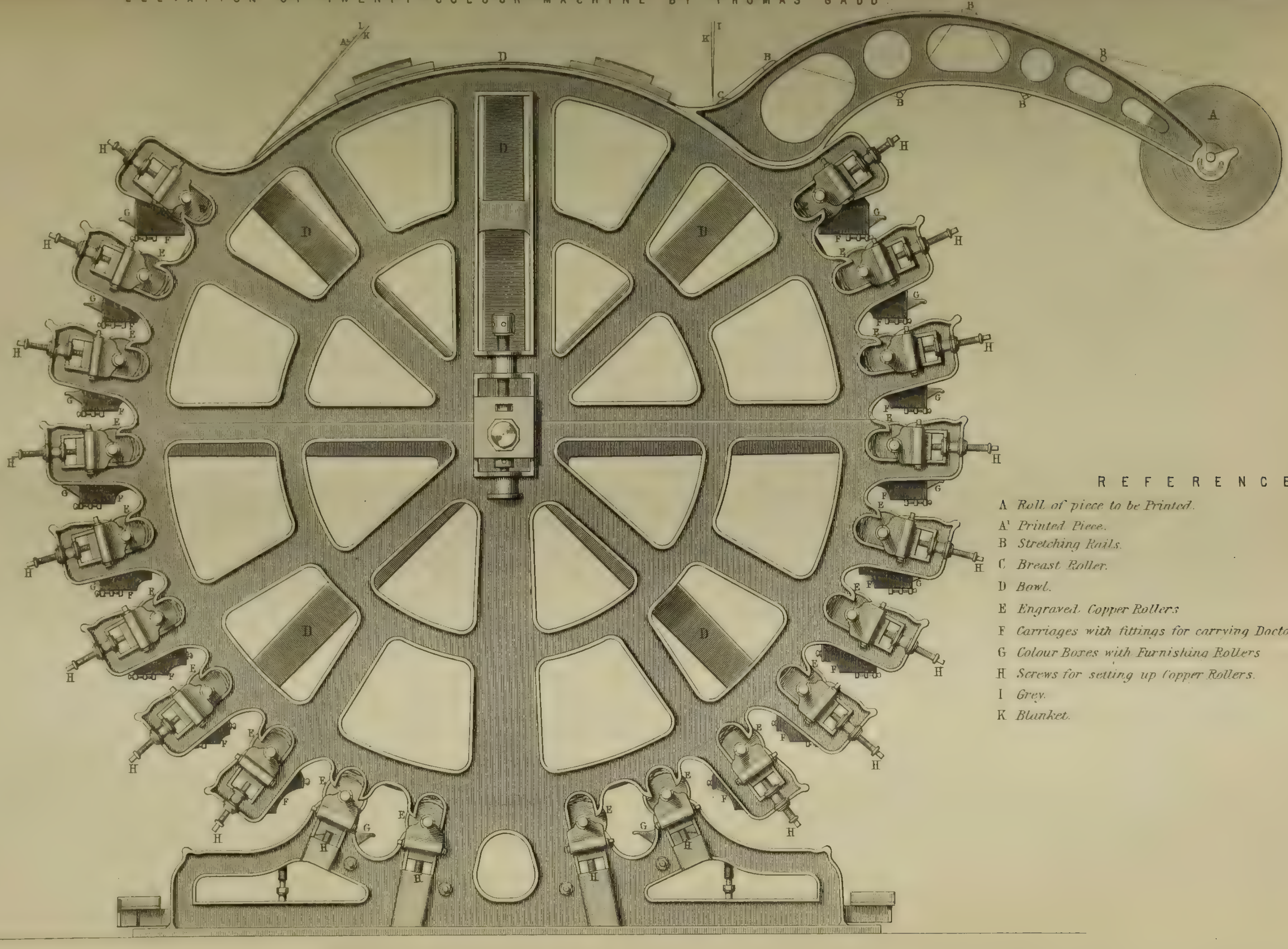
Fig. 6.



Boiling Apparatus.—Most of the materials for making colours are supplied to the colour-mixer in the liquid state, or he finds it desirable to dissolve them himself; and to bring them to a suitable consistency for printing they must be incorporated with some thickening matter, which is usually performed by heat. The pans of a colour shop are made of copper, double cased, and heated by steam; other modes of boiling are quite exceptional. The modern colour shop range consists of a number of these double-cased pans of various sizes, fixed in a cast-iron frame and connected with steam pipes for heating, water pipes for cooling, and mechanical agitators for stirring. In the French system the pans are not fixed in a frame, but are separate and suspended on an axis, through which the steam passes; this permits the workman to get somewhat closer to his work, and allows the emptying of the pan by upsetting. Figs. 5 and 6 show an elevation

CALICO PRINTING.

ELEVATION OF TWENTY COLOUR MACHINE BY THOMAS GADD



REFERENCE.

A	*Roll of piece to be Printed.*
A'	*Printed Piece.*
B	*Stretching Rails.*
C	*Breast Roller.*
D	*Bowl.*
E	*Engraved Copper Rollers*
F	*Carriages with fittings for carrying Doctors and Colour Boxes.*
G	*Colour Boxes with Furnishing Rollers*
H	*Screws for setting up Copper Rollers.*
I	*Grey.*
K	*Blanket.*

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and plan of a colour pan, with agitators, as constructed by Tulpin Frères of Rouen.

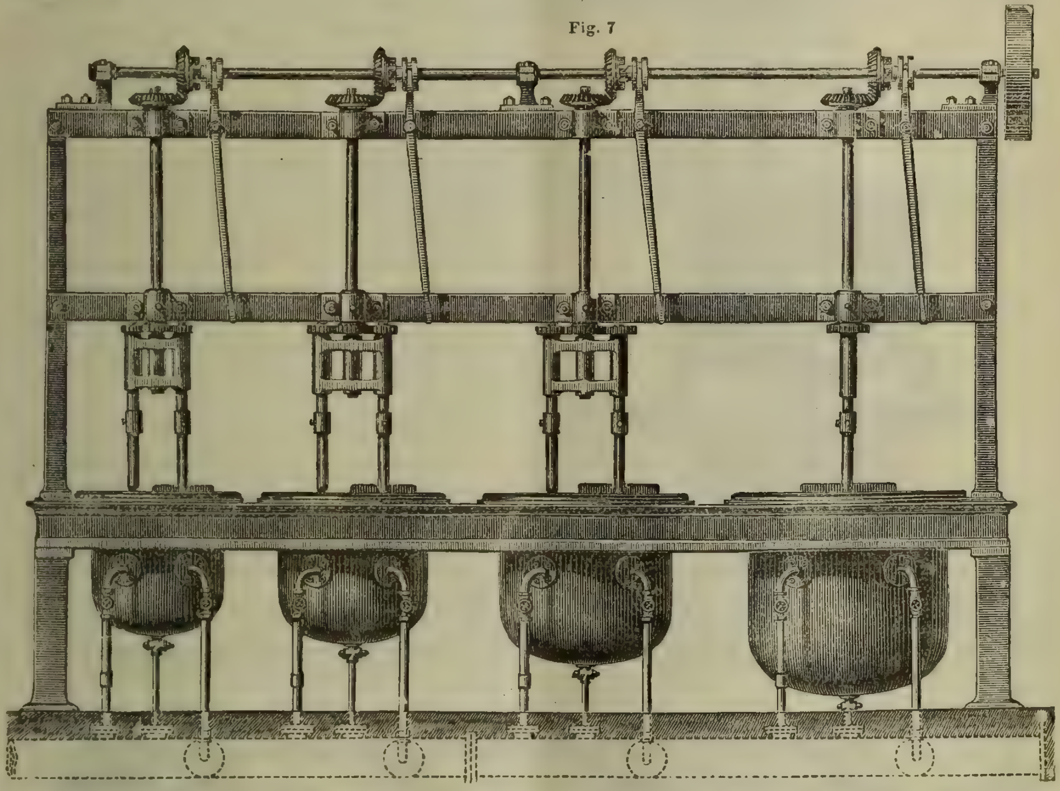
Fig. 7 shows a range by Gadd, and Fig. 9, one by Sumner, both of Manchester. The nature of the agitators are seen in the two sectional elevations of separate pans of Tulpin's and Gadd's construction, Fig. 6 and 8, while still a third variety is seen in Fig. 9.

The French system presents some conveniences, but the pans do not long keep steam tight at the movable parts, and give rise to loss of steam and annoyance. It is found economical to fit steam traps to the waste pipes of the pans, to prevent a waste of steam by blowing through, and to collect condensed water, which is useful for many purposes in the colour shop.

The mechanical agitators, to replace stirring by hand, are of recent introduction; and when well made and carefully managed are both economical and effective. They are not full and complete substitutes for hand stirring, especially with thick paste colours, because they cannot be made to go very close to the pan sides, and a thick pasty mass forms out of their reach which has to be moved from time to time by the stick.

There are very few intelligible instructions which can be given about boiling; the process is simple, and what peculiarities there are in it are special to particular colours. In starch and paste thickenings the material is first made into a homogeneous mass free from lumps, with a small quantity of the liquor to be thickened, and then the remainder of the liquor added and the boiling proceeded with. Gums do not require this preliminary mixing; if the colour will stand long boiling, as in making gum water, the solution will be effected perfectly; but in mixtures of gum and starch it is well to beat up the mixture with a portion of the liquid before adding the whole. The steam should be turned on with caution, and not too powerfully at first; the boiling should not be continued too long, the only object aimed at being to obtain a smooth consistent mass for printing, and too long boiling injures some thickenings. In all ordinary cases it is a great convenience to be able to cool down the boiled colour quickly, and this is done in the modern ranges by turning on cold water instead of steam, and continuing the movement of the agitating arms until the temperature is reduced to the point desired, either for addition of chemicals or for straining.

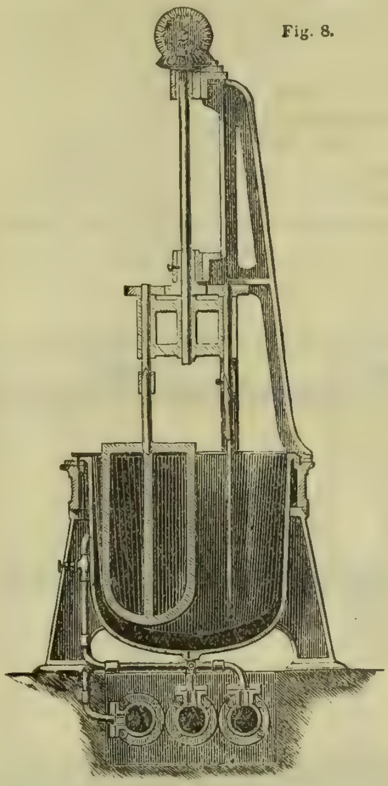
Fig. 7



Gum water is often prepared by simply boiling up in a suitable vessel, and with a naked steam pipe, the mixture of gum and water, allowing for the water condensed in the vessel.

Straining of Colours.—The continental colourists have generally adhered to the system of passing the colours through sieves of wire or haircloth, using the hand or a brush to force thick colours through. The colour is brought by this means into a very suitable state for printing; but it is a very slow and wasteful method, and where the brush is used stray bristles are continually found by the printer under his doctor. The usual hand process in this country is to pour the colour into a square of a strong and open calico, called straining cloth, and then gathering up the corners, by twisting and pressing forcing the colour through. For thick colours this is a very laborious process, and often tests the strength of both the workman and the straining cloth beyond proper bounds. An apparatus for straining by cloth has been recently introduced to imitate the movements of the human strainer. The colour, being inclosed in the cloth, is pressed by being pulled against two small copper rollers, and the twisting is accomplished by an iron arm moving in a frame.

Fig. 8.



The first fairly successful attempt to apply mechanical power to straining is described in Kay's patent (communicated from Dollfus-Mieg), 9th July, 1856. The apparatus consists of a copper cylinder, supported upon centres in a vertical frame; it is provided at the lower end with a brass or copper grid to support straining cloth or wire-gauze, and above with a closely fitting piston, connected with a rack and pinion, which may be moved either by hand or power to force the piston on the colour in the cylinder, and drive it through the straining material. With a good quality of starch for thickening this straining apparatus works very well; with inferior qualities of starch and flour it is not so satisfactory, forcing many impurities through the sieve, which were better left on the other side. Straining by raising a hollow piston covered with straining cloth in a cylinder filled with colour, as in Rippen's patent, or using hydraulic pressure, as in Ridge's patent, may be considered as modifications of the above.

Figs. 10, 11, 12 illustrate the working of Ridge's straining apparatus, which is favourably reported upon by some firms who have it in use. The colour to be cleaned is placed in B, Fig. 11, and the balanced lid, A, closed and secured. The pump being set to work, the piston, D, which carries the straining surface, C, is forced up into the cylinder, and the colour falls into the receiver, G, and thence into a mug or tub, I. Fig. 12 sufficiently elucidates the nature of the straining surface, C. H is a door on the shoot G.

Many attempts have been made to strain colours by atmospheric pressure, but they have not met with much success, unless the arrangement described by Rosenstiehl, and improved by Glanzmann and Witz in the present year, should be found upon further experience to corroborate the very favourable accounts given of it. The apparatus (Fig. 13) consists of a strong riveted wrought-iron vessel, A, having a capacity of about 130 gallons of water. It is fitted with a pressure and vacuum gauge and four pipes; B is in connection with a supply of cold water, C is a steam pipe, D is the suction pipe, and E is the discharge or blow-off pipe; the pipe, D, is in connection with a cast-iron vessel; this iron vessel contains the copper or other vessel, *a*, to receive the strained colour; the sieve frame, F, consists of a short wide copper funnel, which contains the wire-gauze or straining cloth, properly supported, and is fitted to go on the iron vessel in an air-tight manner; K shows details of the sieve frame. J, H, and I show respec-

Fig. 9.

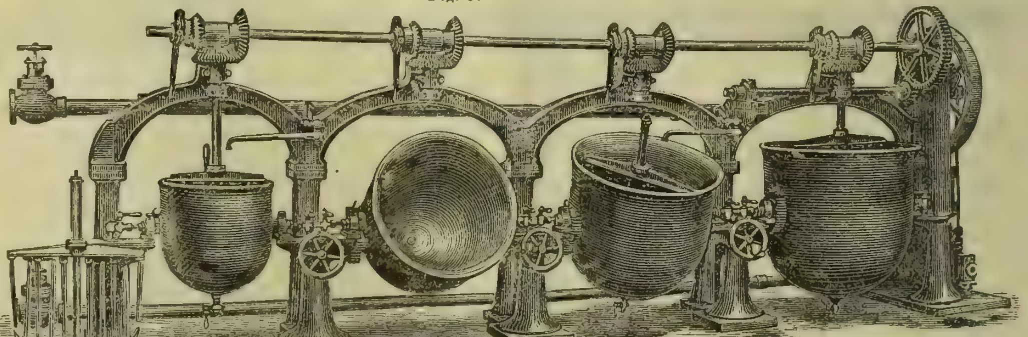
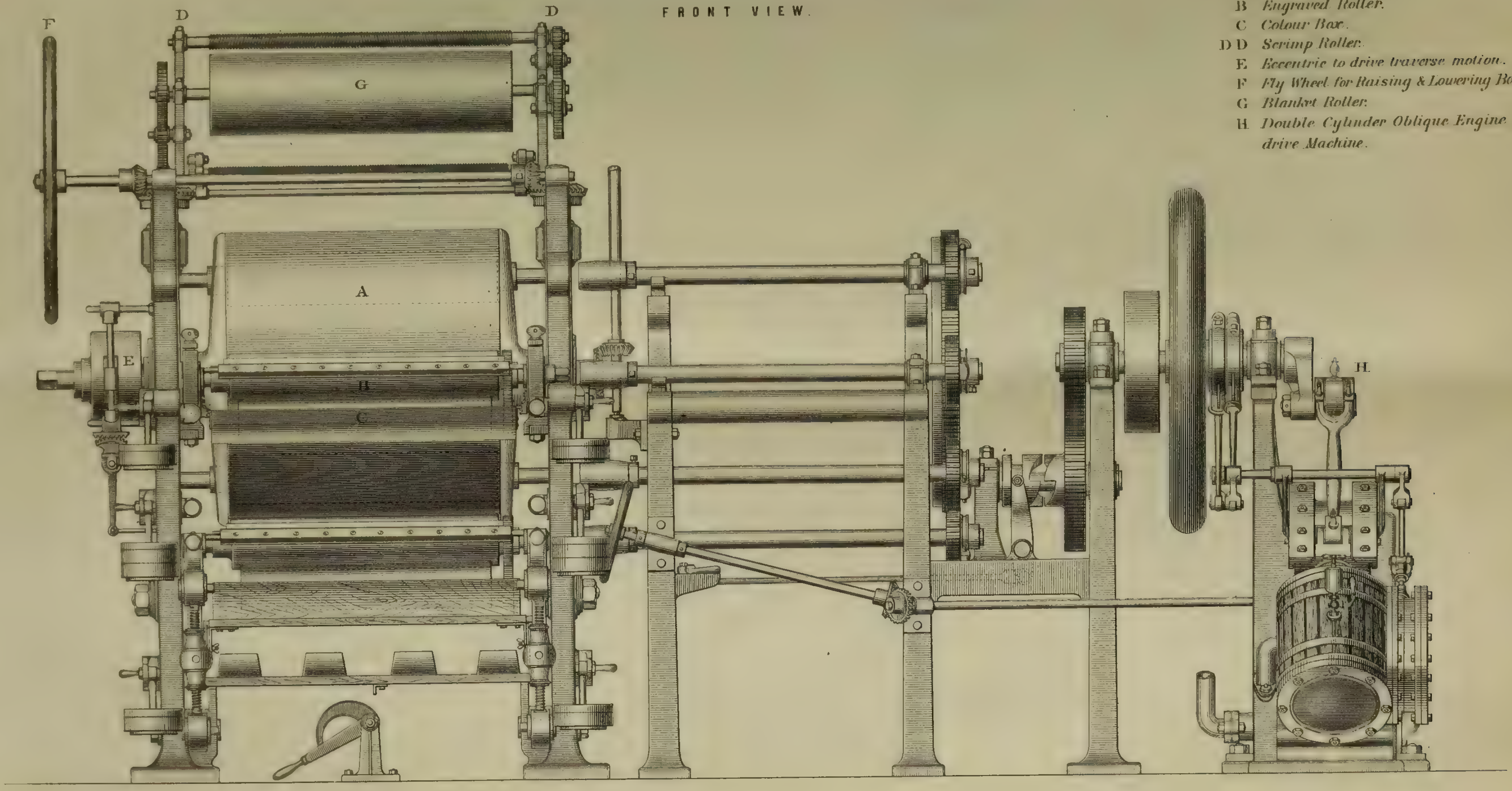


PLATE IV.

CALICO PRINTING.

EIGHT COLOUR PRINTING MACHINE BY TULPIN FRÈRES.

FRONT VIEW.



A	*Bowl or Cylinder.*
B	*Engraved Roller.*
C	*Colour Box.*
D D	*Scrimp Roller.*
E.	*Eccentric to drive traverse motion.*
F	*Fly Wheel for Raising & Lowering Bowl.*
G	*Blanket Roller.*
H.	*Double Cylinder Oblique Engine to drive Machine.*

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tively a water pipe for cleansing the sieve, the sieve as placed upon a support for washing, and a washing off cistern.

The operations consist in making a vacuum in the wrought-iron vessel, as follows:—The discharge tap, E, is opened, and then the steam tap, C, until steam issues from the end of E; the steam is then shut off and the discharge tap left open a moment to permit the excess of steam to escape, and then closed; water is now admitted by opening the tap of B for a minute, and in twenty or thirty seconds a rarefaction, amounting to as much as $27\frac{1}{2}$ inches mercury, is obtained. The colour being placed in the strainer, the tap, D, is opened full for thick colours, but only partly for thin colours, so that the colour may not run through the strainer faster than a workman can keep up the supply. One operation gives a vacuum sufficient to strain from 50 to 60 gallons of thin colour, but only from 25 to 30 gallons of thick colour. The process can be rapidly repeated, so that 25 gallons of paste colour can be strained every five or six minutes; in the course of one hour eight or ten different kinds of colour could be strained to the total amount of 200 gallons. The expense of sieving cloth or wire-gauze for three month's work was three francs.*

Fig. 10.

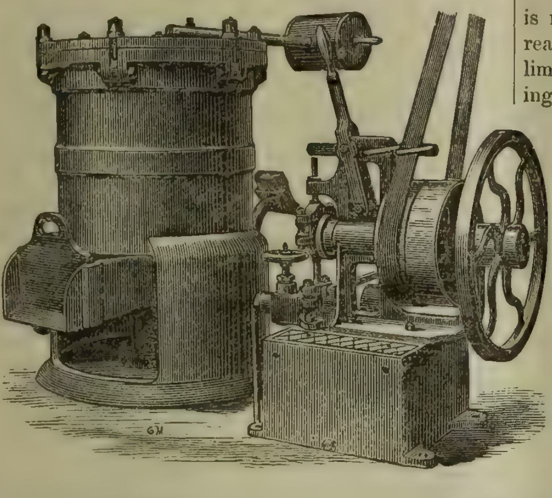
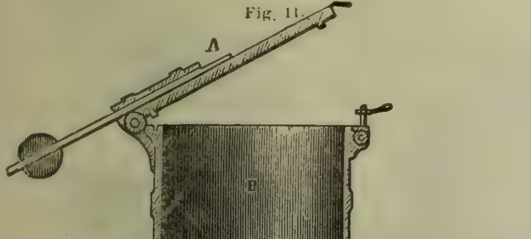
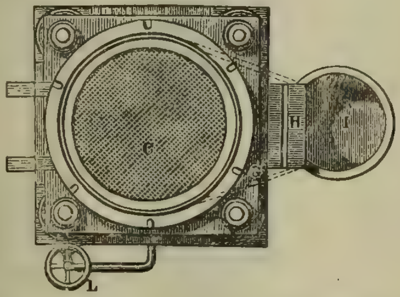


Fig. 11.



Thickening Matters.—A certain degree of viscosity is necessary in colours for printing, if for no other reason that they may not run or spread beyond the limits assigned to them in the design. The thickening mediums employed in calico printing may be divided into two classes. First in importance are those in most general use, and which are only employed to enable the printer to obtain a good impression from the engraving, and to hold up in suspension the insoluble matters which are constituents of so many colours; those of the second class are more limited in number, and not only give viscosity, but cause the colour to adhere, and to be fixed to the cloth by some change which they undergo in subsequent operations. The thickenings of the first class have only a passing or temporary use; they have to be removed from the cloth in some stage of its treatment, are generally a difficulty and hindrance to the full development of the colour, and the finished print bears no traces of them. Those of the second class constitute an integral part of the colour, just as much as the oil vehicles of an artist; they remain upon the cloth when it is finished, and are the cause of the fixity and stability of the colour. To the first class belong the starches and gums, which are soluble in hot or cold water; to the second belong albumin, lactarine, drying oils, and resinous gums insoluble in water. As the application of the second class involves fewer subsequent treatments of the print than the first, they may be conveniently considered at this point.

Fig. 12.



There are only two thickenings of this class of any practical importance, viz., albumin and lactarine. The other thickenings and vehicles which have been tried are gluten, solution of india-rubber, boiled oils, varnishes, and solutions of resins; they have never been largely employed, and do not call for further notice.

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* For full details, see Rosenstiehl, in *Bull. de Mulhouse*, 43, p. 430; also *Bull. de Rouen*, April and June, 1875; and *Textile Colourist*, 1, p. 12.

Albumin was at first obtained from whites of eggs. It was used for fixing artificial ultramarine in the year 1845. At the commencement the fluid white of egg was used. afterwards the dried white, as being more convenient and less perishable. In 1854 PILLANS patented a process for obtaining albumin from blood. The first products were little suited to replace egg albumin; but experience has at length enabled the manufacturer to supply it in a degree of purity hardly inferior to the best samples of egg albumin, and possessing some properties which render it in many cases preferable. Some calico printers, both at home and abroad, have themselves undertaken the extraction of albumin from blood. This can only be advisable where the local conditions are favourable. As this does not often occur, it is sufficient to refer to the description of the process in the *Bulletin of the Industrial Society of Mulhouse*, vol. 39, p. 214.

The solution of albumin is prepared by stirring the powder in cold, or, what is better, in slightly warm water; hot water, of course, coagulates it. Blood albumin thickens better than egg albumin, requiring a less quantity per gallon of water. From 4 to 5 lbs. per gallon of egg albumin should give a sufficiently thick solution. To a certain extent the addition of Senegal, or other gum water, does not conspicuously injure the fixing power of albumin for either pigments or dyes. With one-fourth of gum water, or even one-third, those colours which only require cold washing or slight soaping are good. Mixing with an equal volume of gum water does not destroy the fixing powers of albumin; but the colours will not wear well, and are only fit for low class work. For the application of pigment colours along with alizarin, or any other colour that requires soaping to finish it, the use of egg albumin without gum water is recommended. Blood albumin in these styles may be employed, but it is not so good as egg, neither holding the colours so firmly nor showing them so brightly at the end, probably because this kind of albumin seems to take colour from tinged soap liquors more freely than egg albumin.

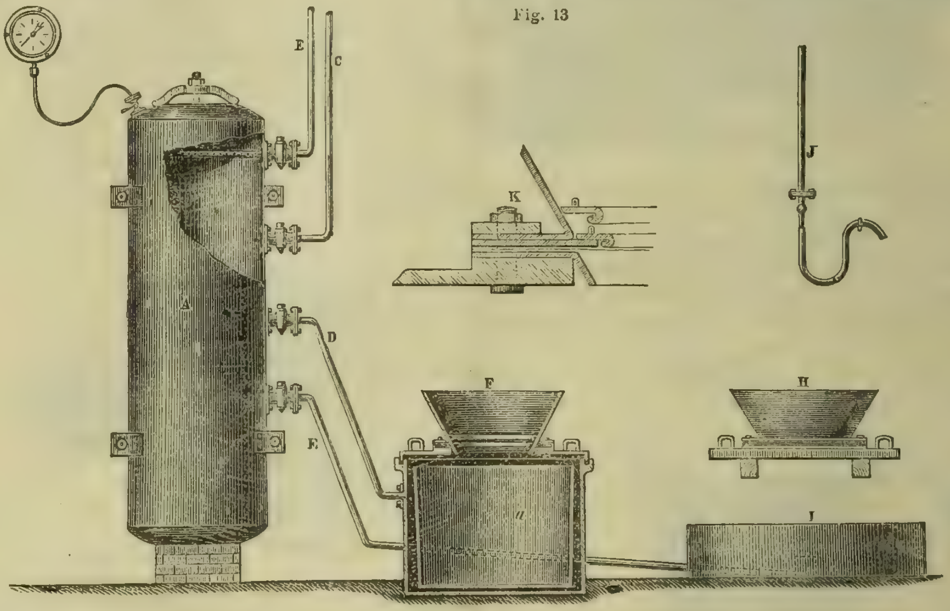


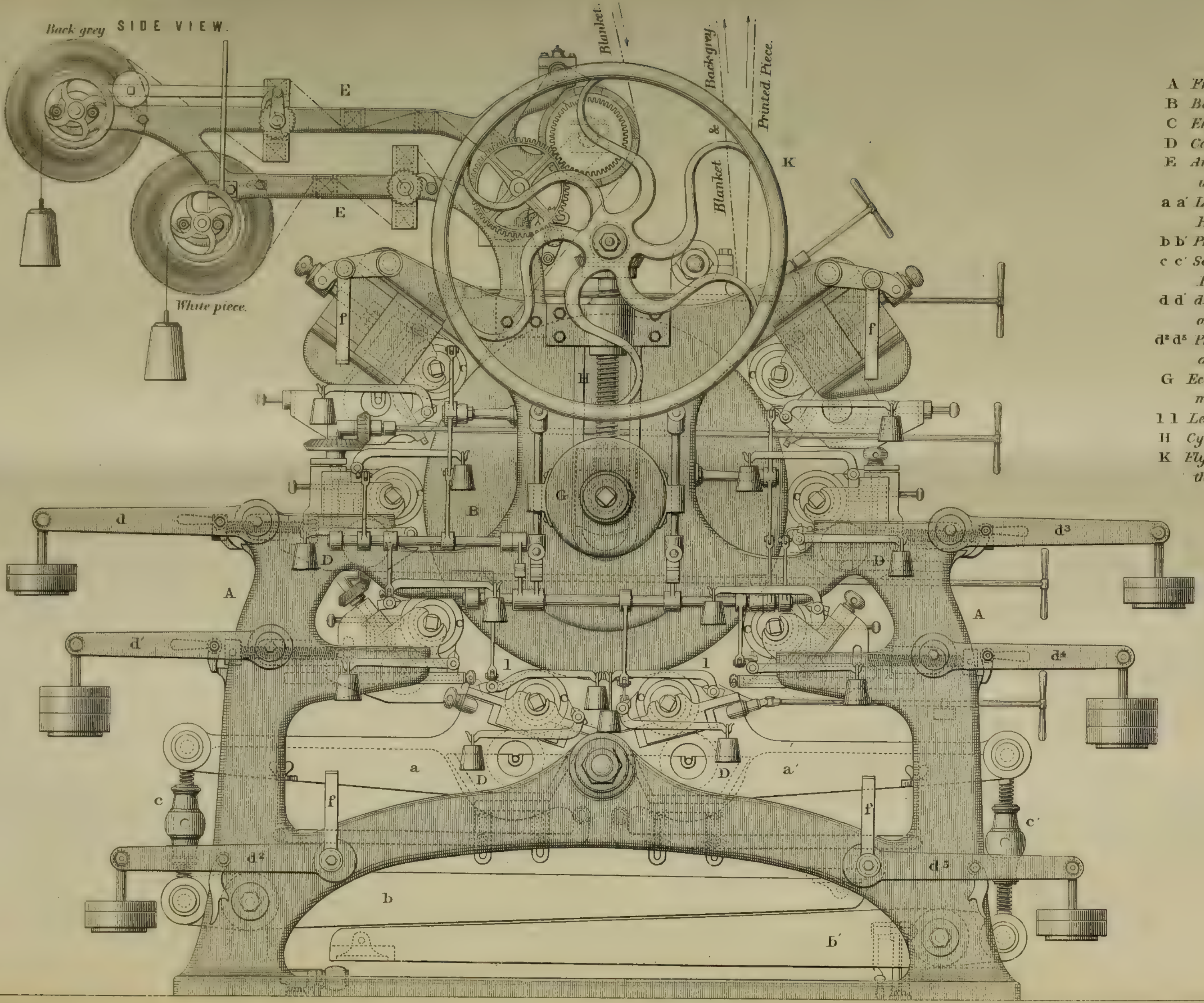
Fig. 13

Albumin solutions are liable to enter into putrefaction and smell very offensively, and there is no perfectly effective means of preventing or arresting this decomposition; but the putrefaction must be very far advanced before the albumin is unfit for use. Solutions which are opaque from insoluble matters become much clearer by slight decomposition, which changes the cellular tissue into a soluble but non-coagulable substance, leaving the albumin practically uninjured.

The working of albumin colours in the machine is sometimes attended with considerable difficulty from excessive frothing, and from the pigments sticking in the engraving. The fault lies either in the albumin being inferior or containing much insoluble matter, or from the solution being unskilfully prepared, or from the pigments being incompletely incorporated with the solution. The two last faults can be corrected by attention and care; the first admits only of alleviation, by dissolving the albumin as hot as can be done without coagulating, settling and straining well, and adding a considerable dose of ammonia, turpentine, or naphtha, as circumstances seem to require and the nature of the colour permits. The pigment green (*Vert Guignet*) is a colour which has given much trouble by sticking in the engraving, and it has been thought necessary to use a brush furnisher, set with tolerable pressure against the roller. This contrivance prevents the accumulation of the pigment in the engraving, and renders it possible to continue printing; but it does no more than keep constantly cleaning out a deposit which

EIGHT COLOUR PRINTING MACHINE BY TULPIN FRÈRES.

SIDE VIEW.



A *Frame of the Machine.*
B *Bowl or Cylinder.*
C *Engraved Rollers.*
D *Colour Boxes.*
E *Arms bearing the Rolls of whites and back-greys.*
a a′ *Levers carrying the Colour Boxes of the 4th & 5th Rollers.*
b b′ *Pressure Levers of the 4th & 5th Rollers.*
c c′ *Screws connecting the Upper and Lower Levers.*
d d′ d³ d⁴ *Direct action Levers of the 2nd 3rd 6th & 7th Rollers.*
d² d⁵ *Pressure Levers of 1st & 8th Rollers acting by f.*
G *Eccentric for driving the Traverse motion of the Doctors.*
1 1 *Levers of the Cleaning & Lint Doctors.*
H *Cylinder Screw.*
K *Fly Wheel for Raising and Lowering the Bowl or Cylinder.*

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ought never to form, and which, if it forms to a notable extent, makes the impression very inferior in fulness and smoothness. In this and every similar case the colour-mixer is bound to try and supply the printer with a colour which will work without a furnisher, or with an ordinary plain furnisher. To continue the case of the pigment green, it has been found possible to print say 50 pieces at once without changing the colour and without brush furnisher, the impression being all that could be desired; and with the same materials put together by another hand, it is impossible to print 3 yards without brush furnisher, and helped by the printer brushing the roller by hand, and after all giving a very inferior impression. This is evidently a fault in manipulation: other faults in the materials may occur. It happened the writer had to use a cheaper kind of the pigment green; and with good albumin solution the printer could not print three turns of the roller without the engraving being filled. The new pigment was examined, and found to effervesce with acids. Dilute nitric acid was carefully added to a quantity of the albumin colour, and the colour sent to be tried again. This haphazard remedy was perfectly successful, and afterwards acetic acid was used in all cases when a similar difficulty occurred. But no skill suffices to get good results from some materials, and there is nothing left for the colour-mixer but to show clearly which of the materials employed is defective.

Albumin may be bad from imperfection in its manufacture or from adulteration. There are no accurate methods of testing small samples chemically, the only trustworthy test being by comparison with a known good quality.

Lactarine, or caseine, is the dried curd of milk. It was introduced by Pattison in 1848. Unlike albumin, it is insoluble in water, but swells out into a state of quasi solution under the influence of ammonia. It forms a smooth white paste, which, when in good condition, prints very well. Pigments and dyes applied to lactarine are sufficiently fast for many purposes, but are inferior to those fixed by albumin. The lactarine solution is liable to spontaneous coagulation from unknown causes. It sometimes goes curdy in the colour box while working, and seldom keeps good for twenty-four hours together, so that a colour which has been once used in the machine can seldom be employed a second time. This uncertainty has much restricted its use; but with care and intelligence it can be profitably employed in the lower classes of prints, or for those styles which do not need much washing off. A high temperature is injurious to lactarine solution, and it should be kept in the coolest place available.

The fixing of colours made with albumin and lactarine is by steaming, and is due to these thickenings becoming insoluble in water by the heat, and so cementing the colours to the fibre that they adhere with great tenacity. Applied in large masses to the cloth, they give it an objectionable harshness and stiffness, which can be partially removed by washing. These colours are sometimes fixed by running the cloth into boiling water, and it is thought that finer shades, especially of ultramarine blue, are thus obtained.

The other thickening matters in use in the colour shop consist of flour, various kinds of starches, and mixtures of flours and starches, natural and artificial gums.

The paste thickenings are those in which the thickening matter swells up upon being heated with water, and are principally represented by wheaten starch and wheaten flour.

Wheaten starch of good quality is one of the most reliable thickenings in use. It thickens sufficiently well at about 1¼ lb. per gallon of water, and next to tragacanth offers the least resistance to the reaction of the constituents of complex colours, and the least obstruction to the passage of mordants from it on to the cloth. It is essentially a watery thickening, containing only from 10 to 12 per cent. of solid matter, has a large capacity for dissolving salts, and penetrates the cloth to a considerable depth, even passing through the usual thicknesses of printing cloth. Unless combined with a considerable portion of soluble salts, as in some steam colours, or unless mixed with some of the soluble thickenings, it is difficult to wash off from the cloth after hard drying; it is therefore chiefly used for those styles which can bear a fair amount of washing as good steam colours, or for dyed styles which can be submitted to a hot water treatment.

The quality of a sample of starch, or its fitness for use as a thickener, can only be ascertained by trial; but the characters of a good starch may be defined as consisting in a taste free from acidity, colour not necessarily bright white, but uniform and free from specks, a fracture not too flinty if in so-called crystals, and a freedom from sand or mineral matter. Carelessly made starch contains insoluble substances which interfere with printing; these are bran, husks, and straw. They can be detected by mixing the starch with cold water, and observing the floating matter, and what settles at the very bottom, and what on the top of the starch. Starch which contains glutinous matters is very unreliable; it is very fermentiscible, and does not give a tenacious thickening. Very white starch is sometimes found weak, probably injured by chemicals used to bleach it. If such a starch requires 1¾ to 2¼ lbs. to thicken a gallon of water, the colour mixer may expect a great disturbance in all his colours arising from that fact. If there are complaints of bad working of starch colours in the machine, an intelligent examination of the starch will generally indicate the cause, and the best remedy is to change the supply. The printer of this day, working fine colours like alizarin red, pink, and purple as topical colours, should spare no trouble or expense to secure a first-rate quality of starch, for it simplifies very much the whole process of printing.

Other starches than wheaten starch have been proposed for use, but none are so suitable; the various paste thickenings in the trade are indefinite mixtures of different feculous matters, the suitability of which for particular purposes can only be known by practice and experience.

Wheaten flour as a thickener is nearly restricted to dyed styles and to mordants of a simple nature, such as red liquor and iron liquor, or mixtures of these two. For this purpose it is extensively employed, as being an economical and perfectly safe thickener. The flour should be of a good quality, finely sieved, free from grit, and while not too rich in gluten, should be capable of yielding a tenacious sound gluten when kneaded in a current of water. Flours which contain a high percentage of gluten never work well; the paste is too tough, and in working some gluten is liable to separate and get into the engraving. Flour in which the gluten has been injured by the weather or bad storage, gives a poor, short, watery paste, incapable of fine printing. The complex constitution of flour makes it unfit for thickening colours containing active chemical agents; and its tenacious adherence to the fabric, and resistance to gentle washing, confine its use to those styles which have to be dunged, dyed, or soaped.

Tragacanth, though called a gum, is properly reckoned among the paste thickenings. It is the most powerful thickening material we have, 1 lb. of it giving sufficient thickness for printing to 4 gallons of water. When of good quality, it yields a very smooth and evenly pasty mass, which when price permits may be advantageously employed in many styles of printing. Containing so much water, it is of course deficient in what is called solidity, does not answer for outlines, penetrates the cloth very freely, and offers so little obstruction to the communication of the mordant or colour to the cloth, that with it the very darkest shades can be obtained of all colours. It washes off well, and on account of the very slight stiffness and harshness which it leaves upon the cloth, it is very suitable for those styles which are either not to be washed off, or which permit of but a very slight washing.

Tragacanth is much employed by continental colourists in small proportion along with starch and gum thickenings. It is believed by them to communicate very valuable properties to other thickenings, and is found in a vast number of recipes where it is never used in English colour mixing.

Natural gums have been used from time immemorial as thickeners for calico printing, and are still extensively used when scarcity and a high market price does not drive the printer to substitutes in the shape of artificial gums. The type of the natural gum is gum arabic, which is entirely soluble in water, and gives a smooth oily fluid, running uniformly and without pastiness; the cheaper gums used in the trade are called gum Senegal, gum Gedda, Turkey gum, East India gum, &c. They are all exudations from similar shrubs and trees, and should only differ from one another by the respective amounts of impurity acquired in a more or less difficult or careless gathering of the gums. In so far the value of these gums might be estimated in the inverse ratio of the insoluble matter, such as sand, gravel, sticks, and leaves, contained in them. But there are trees which yield gummy exudations of quite another character, and so nearly resembling in external characteristics the soluble gums, as not to be easily distinguished from them, and they are used to mix and adulterate the proper gums. A good gum dissolves completely in cold water, but the inferior gums only swell out and give clots and semi-pasty masses, stringy and glutinous. By themselves these pseudo-gums could not be used, but when boiled up with a proportion of genuine gum they become diffused through the mass; and such mixtures may be employed for certain colours and styles where great clearness of colour or smoothness of impression is not required.

Natural gums, unless hand-picked, always contain so much sand that they cannot be safely used for machine printing except first made into gum water; as the gum water while hot is thin, the sand easily settles out. The gum water is made by simply boiling the gum and water together, about 6 lbs. per gallon for thin, and as high as 12 lbs. per gallon for thick gum water. The acidity which developes in gum water in warm weather appears to be owing to the formation of acetic acid, and is not usually detrimental to any of the colours or mordants for which gum water is employed.

The natural gums are usually employed for the lighter shades in steam colours, and for catechu brown in dyeing; for block-printing they can be used for all colours, except the darkest; being soluble they wash off easily, and leave the cloth soft and fine to the touch.

Artificial gums or gum substitutes were introduced in the early part of this century, and have proved at various times a great relief when circumstances have caused an interruption in the supply of the natural gums. They are made by roasting, or calcining, as it is called, the various kinds of starches or farinas, as wheaten starch, rice starch, potato starch, sago flour, &c. By some change which takes place the globules, which were quite insoluble in water, are rendered almost completely soluble; they no longer produce pastes upon boiling, but gummy solutions, but does this at a great expense of material. Wheaten starch, which gives a good paste at 1¼ lbs. per gallon, yields a gum water which requires five times that amount per gallon of water, and of other starches even a greater relative proportion is required to produce a suitable thickness.

The chief artificial gums in use are calcined farina, British gum, and light-coloured soluble gums

Calcined farina is made from potato starch; it is a weak gum, requiring from 8 to 10 lbs. per gallon of water; when properly made it is the most gummy of all the substitutes, and remains fluid for several weeks; from its density and smoothness it is an excellent printing medium, reproducing accurately the finest lines and stipplings of the engraving, and for dyed work giving soft and agreeable shades. The weight of solids in the thickening renders it impossible to obtain dark colours from it, and it is hardly ever employed except for iron mordants intended to yield light shades of purple in madder and alizarin dyeing. Its dark colour is objectionable for topical application; it might be made much lighter than it is usually sold with advantage; being very soluble, it easily washes off.

British gum is made from wheaten starch, roasted either light or dark, giving rise to what in the first case is called light British, and the second to dark British gum. The light gum thickens at from 2½ lbs. to 4 lbs. per gallon; it is half pasty and half gummy, and very suitable for mixing with paste thickenings and for a large class of steam colours. Unless when used with metallic salts in excess, it easily washes off; but in this property regard must be paid to the amount of unaltered starch which it contains, and which is very variable.

Dark British gum thickens at from 5 lbs. to 6 lbs. per gallon of water, and finds its principal employment in dyed styles; it is an excellent thickener for heavier shades of purple from iron liquor mordants; as a thick gum water it is useful to add in certain proportion to flour or starch thickenings; it is the proper thickener for the alkaline aluminate mordant, and generally suits well for all shades which have to be raised cold, as iron buffs and other metallic colours. Compared with calcined farina it is somewhat puffy, and does not yield as fine an impression; and when made from inferior qualities of starch is liable to contain black particles difficult to strain out, which stick in the engraving and spoil the printing; it is also particularly liable to frothing while working.

The light soluble gums are made from different starches by the aid of weak acids or acid salts, and with a much slighter roasting than is employed in the case of the gums just described. When of good quality they are quite soluble in cold water, and the solution is not more coloured than a solution of natural gum of the same strength. They are employed in cases where a coloured gum is objectionable, as in printing woollens, delaines, and paper, and also where a thickening is desired which will easily wash off. These gums are very variable in thickening power, and generally of an unreliable nature with colours which contain metallic salts, excepting alumina, which does not seem much influenced by the saccharine and acid principles contained in most qualities of soluble gums. They should never be used for mordants; and generally every fresh supply should be practically tested before using, on account of the variation in the degree of acidity and other objectionable features of this article.

Of the various other thickenings sold in trade nothing need be said; whatever names they may bear, they will be found to consist of one of the gums described, or mixtures of them with flour or some kind of starch.

The fitness of a colour-mixer depends so much upon his ability in managing the thickenings he has to employ, that he cannot give too much attention to this point, nor study too minutely their properties and behaviour with mordants and the cloth to be printed. The first thing in a colour is that it shall work well, give a good mark, and not trouble the printer. If it does not fulfil these conditions there is something wrong in the thickening. It may be that the thickening itself is of a bad quality, or that unsuitable thickenings have been used, or they have been put unskilfully together. It is manifestly impossible to go into complete detail upon this point. There are hundreds of colours used in printing, and each one has its own peculiar properties; some generalities, however, may be touched upon with advantage.

Frothing in gum colours may be traced to the thickening; it is usually kept down by means of oil, naphtha, turpentine, petroleum, tallow, &c. The non-volatile oils must be used with caution in mordants for dyeing, as they influence the shades, especially purples in madder dyeing.

Scratching of the roller is due to grit or sand, or other hard particles, as crystals of potash salts, burned starch, &c. There is hardly any remedy for fine grit in the gum or starch; it cannot be strained out; there is nothing to be done but to choose thickenings as free as possible from it. To ascertain beforehand the amount of grit, sand, and generally insoluble bodies likely to prove troublesome in a gum, boil it with water containing sufficient muriatic acid to take all the thickness out of the gum, and examine the sediment which deposits after a sufficient interval. Crystals will be found to be generally sulphate, bitartrate, or chlorate of potash. The remedy is to use the colour a little warm, or not to let it cool down to the crystallizing point before using.

The corrosion of the doctor edge, and consequent injury of the roller, is a very troublesome defect, and its cause generally difficult to trace. Probably chlorine in a nascent state exists in such colours as aniline black, catechu brown, or steam colours where metallic nitrates, chlorides, chlorates, and free acids are present; and these are the colours which act upon the doctor. Cases where the doctor edge is roughened by such simple colours as madder red or black not unfrequently occur; they are impossible to explain, and are generally cured by making fresh colour, or even changing the colour to another machine, where probably some slightly different arrangement of the parts prevents or gives rise to a different electrical condition of the roller; for to such condition of the roller or doctor it is usual to ascribe these otherwise inexplicable accidents. Where very active chemical salts are present, such as copper salts and chlorates, the point to attend to is to use the least possible quantity of the salts, to put them into the least active condition, and have as dense a thickening as the colour will permit.

Sticking in the engraving, previously referred to when treating of pigment colours, only takes place when insoluble matters are in the colour, and when the thickening is not of a suitably adherent nature. The colour taken up by the engraving is, so to speak, filtered by the cloth at the moment of the printing, and the soluble and insoluble parts separated; the soluble penetrates the cloth, some of the insoluble rests on the face of the cloth, and some remains in the engraving, and the result is more or less inferior. This defect is common to all pigment colours, to catechu brown and many steam colours. Something can be done to remedy this by the printer using less lapping, and printing with the least possible weight; but the colour mixer should endeavour to obtain the most perfect division of the insoluble matter possible, so that every particle or molecule may be surrounded with a sphere of the thickening, which must be dense enough to hold it in suspension.

A colour working thick in the machine is owing to bad thickening or bad boiling. There is a thin gum and a thick gum or paste badly combined and not completely dissolved, and they separate under the doctor, the thin gradually leaving the colour, which becomes thicker and unworkable.

The depth of shade given by a fixed proportion of mordant or colour bears a close relation to the weight of thickening employed; the smaller the weight of thickening the darker the colour; hence tragacanth and starch give deeper colour than gums. The depth to which a colour penetrates is governed in a great measure by the same conditions; the more watery the thickening the greater the penetration, a point worthy of consideration for dyed styles, where the amount of dyestuff to be used is regulated by the degree of penetration of the mordant. The colour mixer and the printer should aim at keeping colours as much on the surface as possible; only very deep colours are improved by penetrating the cloth, all others are injured.

Steaming Processes and Steam Colours.—Drying after printing by machine is usually accomplished by means of steam chests, of which there are a sufficient number (from fifty to sixty) to insure the thorough drying of the heaviest patterns. The English steam chests are of cast iron, small, and very heavy; the continental steam chests are of wrought iron, riveted, with not more than 1 inch of steam space, and are made 6 or 8 feet long, and may be curved. The point to be attended to is that the pieces are quite dry, yet not heated to an unnecessary extent; that is, the number of chests, the amount of steam on, or the speed of printing, must be so arranged that the piece has not to pass over or close to more than two or three chests after it is dried, and this because many colours and mordants are greatly injured by over drying. On the other hand, under drying must be carefully avoided as the greater evil of the two.

After drying the course taken by the printed piece depends upon what has been printed upon it; and as we gave precedence amongst thickenings to the vehicles for pigment colours, it will be convenient to proceed as if the pieces had been printed with pigment colours, or other colours requiring steaming without the necessity of ageing, and the subsequent processes which belong to dyed styles.

It is believed that the process of steaming for fixing and developing colours is an English invention, practically applied at the beginning of this century. It was probably independently discovered in France about the same time, for after the close of the wars, and the renewal of peaceful intercourse in 1815, we have it recorded that two Frenchmen came to sell the discovery of steaming to the British printers, but were met everywhere with the statement that the thing was old and well known. The one chief way of steaming pieces now practised is to have a steaming box, house, cottage, or kennel, generally constructed of iron and preferably of boiler plate riveted, and of a circular or oval form, provided with a door which can be securely and tightly closed, and pipes to admit and let off steam. The goods to be steamed are hung by various contrivances upon a frame which can be rolled into the steaming house, and are there subjected to the action of the steam.

Besides these modes of working, arrangements have been devised for continuous steaming, but they are too recent in their application to enable anyone to say whether they will turn out of practical advantage to the trade. Reference may be made to the patents of Cordillot & Mather, Feb. 9, 1875; Smith, April 10, 1875; Jones, August 21, 1865; and also Thierry-Miegs process, April 29, 1875. (See *Textile Colourist*, vol. i. pp. 97, 98, 106, 400.)

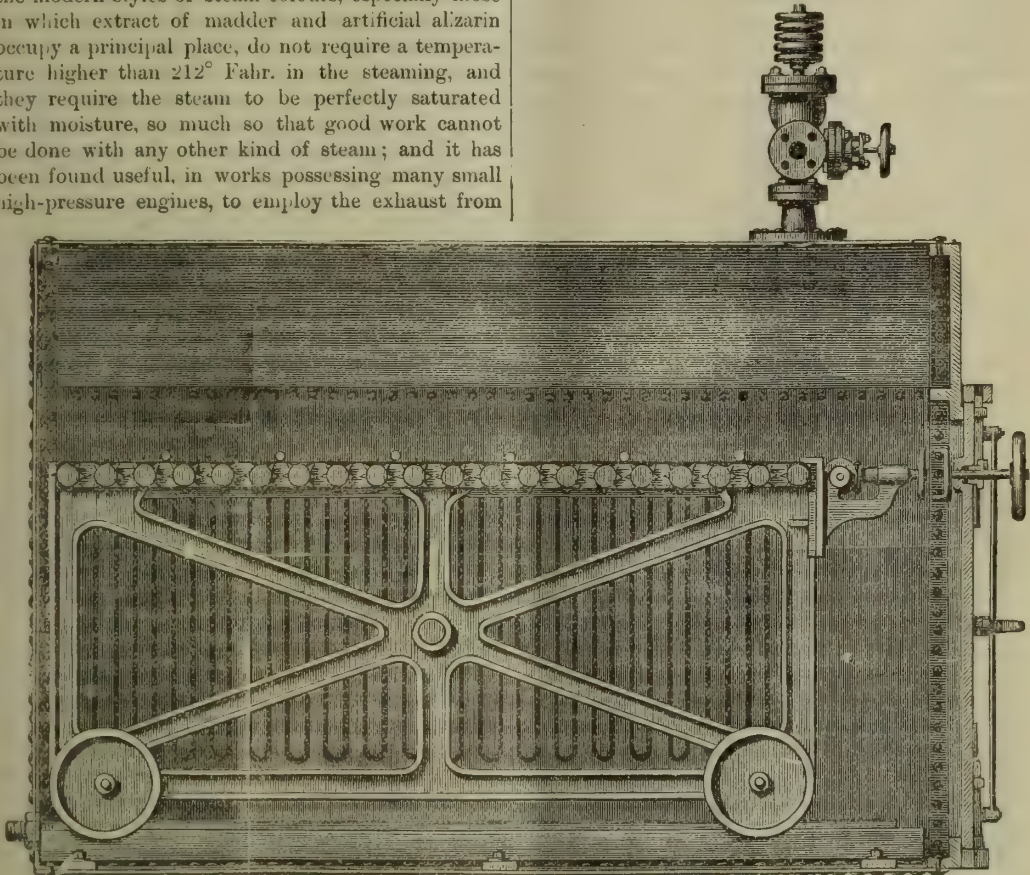
Fig. 14 shows a sectional elevation of steaming cottage with the goods hung on the frame, which travels on a railway. Fig. 15 is an end view of the same with the door closed. The wheel on the left of the door is connected with a light shaft running the length of the frame, and geared to each of the suspending rollers. By turning the wheel the position of the cloth is changed, and irregularities from contact with the rollers in great measure avoided.

Pigment colours fixed by albumin are the simplest of all colours to steam; they require nothing but thoroughly heating through, and they are not easily injured by carelessness or unskilfulness. Yet this facility has led frequently to under steaming, which is shown when the goods are washed off, by the loss of colour all the length of the piece in its centre, while it is perfectly fixed at the edges. For other colours on calico the steaming operations may present more or less difficulty, according to the number of colours on the print and the delicacy of the shades to be obtained. Only a few cases can be cited and general rules given. The great bulk of colours on calico require nothing but a sufficient quantity of low pressure and moderately damp steam. Most of the inferior results traceable to steaming are owing to having the steam too dry and too hot, and this is sometimes difficult to avoid if the steam be supplied at a pressure superior to say 10 lbs. on the square inch. There may be water at the bottom of the steaming box, and the steamer supposes that therefore the steam must be wet; but notwithstanding this the steam may be so dry that the goods never get really softened, and the colours are not in a position to develop themselves or combine with the cloth. It is desirable that the steaming boxes should be supplied from low pressure boilers, working at from 6 lbs. to 8 lbs.; or if there is only a high pressure supply it is useful to have a receiver of strong boiler-plate, having a capacity of several cubic feet, placed between the boiler and steaming box, provided with valves and gauges, so that the steam may be reduced under the eye of the steamer himself. This arrangement is in use on the Continent, and it is a palliative, but nothing more; for dry steam does not become damp with that rapidity which would at first sight seem likely, and cannot instantly saturate itself, even in contact with water. Many of the modern styles of steam colours, especially those in which extract of madder and artificial alizarin occupy a principal place, do not require a temperature higher than 212° Fahr. in the steaming, and they require the steam to be perfectly saturated with moisture, so much so that good work cannot be done with any other kind of steam; and it has been found useful, in works possessing many small high-pressure engines, to employ the exhaust from these engines for steaming madder extract and alizarin goods, and thus insure a really moist steam.

In some cases of mixed and woollen goods, with dark colours, a high pressure of steam is thought desirable for at least a portion of the time during which the goods are under treatment.

In order to prevent the liberated acids or other vapours from injuriously affecting fine colours, a large volume of steam should be allowed to blow through during the first part of the steaming. In steaming alizarin styles well covered with colour, a very large quantity of acetic acid is set free, which may influence other colours, and even rapidly corrode the iron plates of the steaming box. Vessels full of slaked lime have been placed at the bottom of the box to absorb this acid, and greys padded in a chalk mixture wound on with the pieces, but it is preferable to have a free current of steam blowing off.

Fig. 14.



The time to be allowed for steaming varies from half an hour to three hours, depending upon the styles, the quantity of cloth, and the pressure or volume of steam; those colours, such as dark chocolates, cochineal scarlets, blacks, and extract and alizarin colours, which do not contain a large proportion of soluble salts, and which dye, so to speak, the fibre, demand the longest time in steaming; but the composition of these colours can be largely varied, and no general rule can be given.

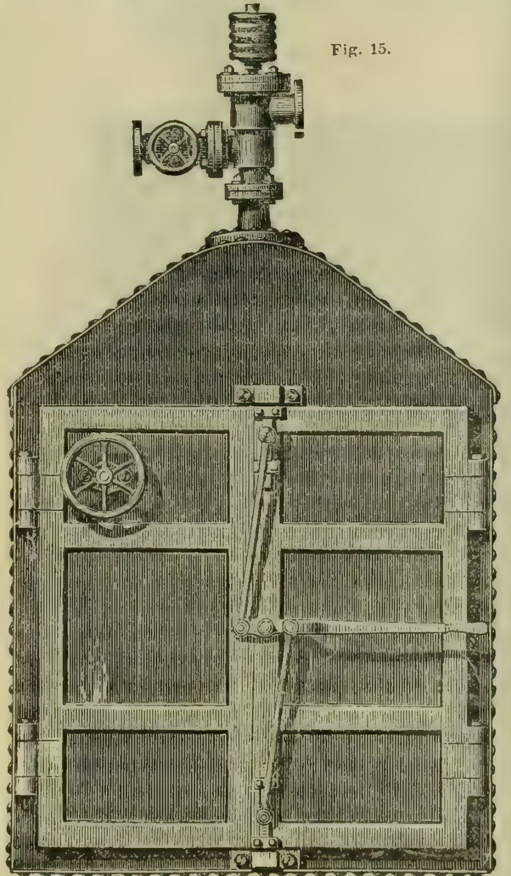
To avoid unevenness much care is required in some styles, and steaming boxes are usually provided with apparatus by which the cloth can be moved without interrupting the steaming, so that, as far as possible, every part may receive a due allowance of steam; and in some cases the pieces are hooked on a frame or suspended by cords, in order that the steam may pass freely through every fold.

To prevent marking off a grey piece is frequently wound on with the printed piece. It is desirable to ascertain the absence of matters in the grey which might injure the colour.

Colours containing copper and lead are liable to become darkened by impure steam containing sulphuretted hydrogen. This fault is in the boiler, and no good can be done until the boiler is cleaned; some relief, however, is obtained by hanging up calico saturated with acetate of lead. A certain metallic lustre, apparently not due to sulphur, is frequently developed in some dark steam colours; this arises from the colour itself, and is generally remedied by addition of sal-ammoniac to the colour. The darkening and sometimes almost decolorizing of pigment orange made from minium, is owing to acid in the steam, which decomposes the colour, forming the puce-coloured oxide of lead. This does not occur with orange made from the chromate of lead.

Accidents from drops of condensed water, or running caused by undue condensation of steam upon the cloth, are to be guarded against by practical precautionary measures, such as warming the box before commencing, seeing that the cloth is not too cold in entering, and covering exposed parts with thick woollen blanket.

Fig. 15.



The majority of steam colours are simply washed in water after steaming, and require only finishing, others require special treatments, which are more properly considered further on.

Mordants for Dyed Styles.—We now proceed with the dyed styles, the colours or mordants on which require some kind of ageing, fixing, and dyeing, and as the successful working of these styles depends greatly upon a knowledge of mordants, it is desirable at this point to consider them.

The various fibres used in manufacturing textile fabrics differ considerably in their behaviour to chemical agents, and it is impossible to treat them generally as having the same character. The following remarks are to be considered as applied to cotton goods when other fibrous matters are not expressly named.

Of all the organic colouring matters which exist in nature, and all those which modern chemistry has manufactured by art, there are hardly half a dozen which give a tolerably full shade to cotton without the assistance of some intermediary agent; and with the exception of indigo blue and aniline black, both of which are applied to cotton in an unformed state, they are all of the most fugitive and unstable character. The most powerful and most valuable colouring matters, as madder, alizarin, logwood, brazil wood, cochineal, quercitron, bark, and fustic, however applied to cotton, communicate to it only a dull stain, which can be nearly all washed out with water, and which is incapable of resisting the action of air and light. At a very early period it was discovered that certain mineral salts, and some vegetable and animal substances, were capable of contracting a very intimate alliance with cotton; and though these substances themselves possessed little or no colour, they enabled the cotton to retain the colour from dyestuffs in a very perfect manner. In modern times the number of these intermediary substances has been increased by some additions, and they constitute the class of mordants, which name is properly applied to any matter which has the power of combining at the same time with the cloth and the colouring matter.

The mordants may be divided into three classes—first, those derived from the animal kingdom; secondly, those from the vegetable kingdom; and thirdly, those from the mineral kingdom.

The animal mordants are albumin, lactarine or caseine, and gluten. It will be observed that these are all highly nitrogenous bodies, and of complex composition; they are soluble in water or alkalies, and by heating become insoluble, and thus can be securely fixed on the cloth. Their use as mordants is but limited, and at the present time does not extend beyond the application of aniline colours. The treatment is very simple; a solution, say of albumin, is made, and the colouring matter added in proper proportions; the mixture printed and steamed, when, if required, the goods may be washed or slightly soaped. If the albumin alone were printed and steamed, and then the goods dyed in a solution of the colouring matter, the albumin would be found to act as a mordant; but it is not advantageously used in this way. The solution of lactarine has been largely used to mordant or prepare calico and mixed goods for printing steam colours upon, and very pleasing effects were produced; but the expense was considerable, and the processes now little used; lactarine is a suitable mordant and thickening for the topical application of the coal-tar colours, which are not injured by alkalies. Instead of the commercial lactarine, inferior qualities of cheese made from skim milk, and deprived of fat, may be dissolved in soda or ammonia. Gluten has been applied, but does not seem well adapted for the purpose.

Glue or gelatine might be included in the animal mordants, but its properties differ considerably from the others; it does not become fixed or insoluble without the aid of some vegetable or mineral substance.

The vegetable mordants are of a dubious nature, and hardly any of them can be said to satisfactorily fulfil the real conditions of a mordant, and it is probable that further research may remove them out of the class altogether; they are confined to the various astringent substances, whose type is tannic acid, and to fatty matters, represented by olive oil. Both astringents and oils can combine in an intimate manner with cotton, and they have a certain but very restricted affinity for colouring matters, and only act as perfect mordants for the majority of colouring matters when they are used in conjunction with mineral mordants. However, tannin or tannic acid is employed to fix several of the aniline or coal-tar colours by simply thickening, printing, and steaming; the result is not very good, whether regarded as a fast colour or a brilliant one. By passing the steamed goods through metallic salts, such as tartarized antimony, as in Lloyd and Dale's process, some farther degree of stability is attained; but on the whole, this use of tannin matter is very limited in printing, though very extensively employed in piece dyeing, either with or without other mordants.

The use of oily compounds to fix the aniline colours seemed at one time to promise useful results. The oleate of ammonia was employed with some success, but it has not satisfied practical requirements. The mixture of oil with the majority of colours for printing has nothing to do with its power as a mordant, although, as before stated, its mordanting powers sometimes interfere in a hurtful manner.

The use which is made of oil in turkey red dyeing is only remotely connected with this subject; it is but little understood, or cannot be used in a similar way in calico printing. It has often been proposed to prepare calico for printing various colours by a modification of the oiling process used in turkey red dyeing; but it is not proved that any advantages have resulted from the attempts thus made to give increased stability or brilliancy to topically applied colours.

The mineral mordants are those most employed for general dyeing purposes, as also for calico printing, and consist of salts of the metals, and chiefly those of alumina, iron, tin, and chromium.

Alum and salts of alumina have been in use from ancient times, though it cannot be clearly shown that the acetate of alumina, as at present employed, was known more than about a hundred years back; the oldest recipes contain several ingredients of apparently a useless nature, such as arsenic; but it is only stated in a few cases that the arsenic was to be dissolved in potash, which quite changes the nature of the addition, and with the use of vegetable acid solutions at the same time produced a species of mordant approaching to the modern red liquor. In 1742 there was a patent granted to Daniel Chappel for a mordant composed of alum, arsenic, white argol, chalk, and saccharum saturni (acetate of lead), all mixed together in liquor thickened with gum arabic. If the proper proportions were used, and as little as possible of the arsenic and argols, a perfect red mordant for light reds at least could be made by the patented process, which contains the first distinct mention known of the use of acetates to decompose alum.

Alumina may be considered as the perfect type of a mordant. It is itself colourless, and has therefore no physical or complementary optical influence upon the shade produced by its combination, and is capable of being saturated to a high degree with most colouring principles, and giving distinctive and definite hues with nearly all dye woods.

The acetate of alumina of the printers is prepared from alum, or sulphate of alumina, and acetate of lead or lime; the proportions to be used may vary within narrow limits, and for special styles particular additions are made generally without any necessity. It is sufficient to give here two practical recipes for each of the ingredients for red mordants which have been in use for several years, and which properly thickened and reduced have satisfied every requirement for reds, pinks, and chocolates. A strong red liquor is made by taking 100 gallons of boiling water, 480 lbs. of alum, and 384 lbs. of white sugar of lead; this should stand at about 20° Twaddle, and is the strongest red liquor that need be made. Another standing at about 12° Twaddle is composed of 150 gallons of water, 460 lbs. of alum, and an equal weight of acetate of lead. It will be observed that these red liquors, besides their difference in strength, must have an essentially different internal composition, and, it may be concluded, a very different behaviour in the various conditions in which they are placed in practice. This is undoubtedly so, but not to so great an extent as might be imagined. The second red liquor was found to be very well suited for full reds, as well as for chocolates; but it is on the whole what may be called an unstable mordant, and could not be depended upon when reduced with four or five volumes of water for light reds and pinks, even with a free addition of acetic acid. The first red liquor was found of very general applicability in dyed styles, and was used with confidence for all colours, and preferred for everything except for a full bright red, for which particular colour it never gave so good a result as the other. It is not unusual in making red liquors from acetate of lead to add about 10 per cent. of the weight of the alum of crystals of carbonate of soda, after the principal ingredients have been well mixed, or an equivalent amount of ground chalk; on the large scale this addition may be found economical, but for colour shop practice it is generally considered safer to use a little more acetate of lead, if necessary, than trust to the effect of either soda crystals or chalk. Acetate of lime is largely used as a substitute for acetate of lead, and would answer nearly as well if its quality could be depended upon with as much confidence as can be reposed on the acetate of lead; but acetate of lime, either dry or in solution, is liable to variations in composition, which have produced very disagreeable irregularities in practice. Sulphate of alumina is also used instead of alum, but like acetate of lime it does not present any external appearances by which its purity or strength can be determined; it is not constant in composition, and cannot consequently be depended upon with the same certainty as the well-defined crystals of alum. For these reasons the majority of colour-mixers, who make their own red mordants, adhere to alum and white acetate of lead; but with sufficient chemical knowledge to ascertain the real value of the materials, perfectly satisfactory results can be obtained from acetate of lime and sulphate of alumina, and there is some economy in employing them. Two red liquors which have been in use for many years, in which acetate of lime and sulphate of alumina are employed, were made as follows:—50 gallons of acetate of lime liquor marking 24° Twaddle, placed in a copper pan, and heated up to 140° Fahr., and 200 pounds of ammonia alum in a crushed or roughly powdered state added. The temperature is maintained at 140° Fahr., and the mixture kept constantly stirred until the alum is perfectly dissolved, which may take two or three hours, then 12 lbs. of ground chalk are added in small portions with stirring. The resulting red liquor should mark about 20° Twaddle, and should be good for all dyed reds and pinks. It will be more or less darkly coloured according to the colour of the acetate of lime; the sulphate of lime bottoms are very bulky compared with sulphate of lead bottoms, and retain a great quantity of mordant, which can be separated either by pressing or washing. Another red liquor was made from 90 gallons of the same acetate of lime liquor, and 272 lbs. of sulphate of alumina, with addition of 34 lbs. of ground chalk, using the same general procedure. The resulting red liquor marks about 16° Tw.; it is capable of yielding good reds and chocolates, and was found to work well with considerable addition of tin crystals in the case of reds required to resist covers of purple or chocolate.

The only other alumina mordant in use for dyed styles is the aluminate of potash. Its use was suggested at a comparatively remote date, but it has never come into general employment. The usual method of preparing it is by adding powdered potash alum, or sulphate of alumina, to boiling caustic potash; for each gallon of the latter marking about 54° Tw., 3 to 3½ lbs. of sulphate of alumina may be employed. The heating and stirring is maintained until the salt has quite disappeared; upon cooling sulphate of potash crystallizes out, and the clear liquor is the mordant. It cannot be properly thickened by starch, flour, or the natural gums; it is best thickened with well calcined wheaten starch. In some works it is considered that aluminate of potash is the most preferable mordant for pinks; but the opinion is by no means general, and as the fixing requires special means not in use for the general run of dyed goods, it is not largely employed. It is difficult to say what advantage it has over the acetate of alumina mordant for madder or alizarin pinks, except in the printing. It gives a very clear impression, but what is most important, it is not injured by too much heating in the steam chests. The weak acetate of alumina mordants intended for pinks, whether thickened with paste or gum, require very great care in drying after printing—if too much heated the mordant is greatly injured; with aluminate of potash mordants the hardest drying does no injury. In other respects the aluminate is more delicate and sensitive than the acetate, more easily injured in the fixing, and more easily takes up impurities, organic or inorganic, from inferior qualities of water.

The nitrate and hydrochlorate of alumina are used to a small extent in steam colours, and in certain combinations the oxalate and tartrate of alumina occur.

Mordants of iron are of ancient use; the only one of special importance in calico printing is the acetate of iron, known generally as iron liquor, or black liquor. The first crude acetate of iron was probably made by steeping old iron in the sour acetous liquids derived from the fermentation of rice or flour: such mordants were used by the Hindoos. The making of iron liquor was patented in 1780 by FLIGHT; he directs iron to be steeped in "water drawn from tar or tar oil, and the liquor mixed with starch, flour, or gum, to give blacks and purples;" by this water we may understand pyroligneous acid, and this process may be said to be the one used at the present day for making the best quality of iron mordant. Two years later, in 1782, BOOTHMAN patented the method of steeping iron filings, iron hooks, or other thin iron, in a mixture of water with wheat, flour, barley, bran, or any other vegetable that will produce an acid when mixed with water, being practically the method used at earlier periods by native Indian printers. On the Continent iron liquor is yet made in certain parts from sour beer. No form of acetic acid seems so suitable as the pyroligneous for making iron liquor, if the acid does not contain too much non-volatile matter. The small amount of organic matter present appears to be useful in preventing the too rapid oxidation of the iron, which would be injurious for all delicate shades; hence the pyroligneous acid is preferable to pure acetic acid, for in the latter case it is found that dilute solutions are very easily oxidized and decomposed, the iron takes the form of the peroxide, and the solution loses available iron, or becomes very uncertain in its composition, and irregular in its results; while the pyrolignite keeps well, as it does not appear that the iron ever attains the maximum degree of oxidation.

Iron liquor is seldom made in any print works in Great Britain; it is found in commerce as a dark-coloured fluid, marking from 24° to 28° Tw. On the Continent it is to be found in a very concentrated syrupy state, about three times the strength of the ordinary home supply, perfectly miscible with water, and of excellent quality.

Iron liquor can be thickened with any of the usual thickenings of good quality, but its powers of fixing on fibre are very much weakened by the presence of any sugar or saccharine principles in the thickening; therefore wheaten flour, injured by heat and damp, or those gums and other thickenings made by means of acids, may be found to give very inferior results with diluted iron mordants.

No other iron mordant is used in calico printing; the sulphate and nitrate of iron are largely used in piece dyeing. The iron buff of the calico printers is very rarely used as a mordant; it is an acetate or sulpho-acetate of iron made from sulphate of iron and acetate of lead. For the topical application of extract of madder or alizarin purples or lilacs, although good results can be obtained from a fair quality of commercial iron liquor, the colour mixer will find it advantageous to prepare his own liquor from sulphate of iron and acetate of lime, or acetate of lead; the white acetate of lime being preferable, and used in slight excess, so as to have some acetate of lime in solution.

Tin mordants are very rarely used in calico printing in the way that iron and alumina mordants are used. The oxides and salts of tin do not belong to the same chemical group as those of alumina and iron, and though they possess strong affinities for both fibre and colouring matter, it has not hitherto been found possible to prepare any mordant of tin which can be thickened and applied to calico in the same way that the salts of the other two metals can be used for dyeing. An apparent exception to this statement is the so-called garancin orange, made from a salt of tin, an acetate, and decoction of Persian berries, which being printed along with other mordants, goes through the dunging and cleansing process, and is dyed up in garancin with them. In this case it might be supposed that an acetate of tin was acting as a real mordant, the same as the acetate of alumina, and producing a different shade of colour; but it is evident that the garancin orange is little more than a spirit yellow, which by care can be made to stand the garancin dye, and absorbing some red, yields an orange hue of but little stability compared with the other colours. When chloride of tin is added in moderate proportion to acetate of alumina mordant a complex reaction takes place, which is not fully understood; but the mixture has some of the properties of the chloride of tin, it can resist and even discharge iron mordants, while it dyes up good and full shades of red with madder and garancin. Upon analysis of the mordant remaining upon the cloth, a certain quantity of tin is found along with the alumina, forming a compound mordant, which is believed to have a greater affinity for colouring matter and fibre than either metal separately, because the mordant cannot be discharged completely by the same acids which would discharge an alumina mordant; but in point of fact it is the tin only which resists these acids. The alumina is easily dissolved out, and the amount of tin remaining is insufficient to dye up anything which can be properly called a colour. The powers which tin salt exercises in what are called resist reds is in great measure due to its deoxidizing powers, and converting a certain portion of the acetate into the muriate of alumina. If calico be prepared with chlorate of potash, as it is for some purposes, it will be found that a resist red, which is quite capable of throwing off purple covers when printed upon ordinary calico, fails to resist them when it is printed upon the prepared calico, and this clearly because the tin is raised by the chlorate to its maximum degree of oxidation.

Although salts of tin cannot be used in calico printing for dyeing, they are extensively used in steam colours as mordants, and are also largely employed in preparing or mordanting the whole surface of the calico previous to printing steam colours.

The chief compounds of tin in use are the crystals of tin, called also muriate of tin, chloride of tin, and stannous chloride; a solution of the same salt called liquid muriate of tin; the liquid bichloride of tin, stannic chloride, is not much used; the oxymuriate of tin, which is generally a mixture of the two chlorides, is used for spirit colours; and the stannate of soda, which is the principal salt used in preparing or mordanting cloth before printing.

The preparation of calico with tin is important for the majority of steam colours; it is simple and certain, if good materials and ordinary care are employed. The cloth is saturated with a solution of stannate of soda of a strength proportioned to the styles to be printed; it is then passed into dilute sulphuric acid, washed and dried. The points to be attended to are an even uniform impregnation of the stannate, a sufficient quantity of sulphuric acid, a gentle and not too hard drying after washing. Badly prepared cloth may be usually traced to an inferior quality of stannate, or to a deficient quantity or strength of sours. For styles requiring a very strong prepare the process of passing in stannate and acid may be repeated two or three times, the moisture of the cloth being as much as possible expressed between the treatments. For woollen mixed goods there are various methods of preparing. Some systems employ the stannate only, others the acid salts only; others again prepare in stannate, and then over again in bichloride or oxymuriate, the object being to deposit as great a quantity of oxide of tin upon the cloth as can possibly be retained by it.

The salts of chromium present much analogy in their chemical constitution to those of iron and alumina, and have been prepared as mordants; but until these few years past have had but a very restricted application, and even at the present time are scarcely ever used, except as constituents of steam colours. Although chrome alum is an article of commerce, and it could be employed in the same way as alumina alum to make the chromium mordants, the colour-mixer usually prefers to operate upon the bichromate of potash as the more convenient source of chromium for his purposes. The usual mordants of this metal in use are the acetate and nitrate, and they may be prepared by one of the following methods:—For acetate of chromium, 26 lbs. of bichromate are dissolved in 5 to 6 gallons of boiling water in an earthenware vessel, and 32 lbs. of strong sulphuric acid carefully added, then 6¼ lbs. of wheaten starch are added in small portions, so as to keep the effervescence within controllable limits; when the action is complete, and the liquor somewhat cooled, a solution of 50 lbs. of white sugar of lead in 5 gallons of hot water is well mixed with it, the sulphate of lead deposits, and the clear liquid floating above is the acetate of chromium.

Nitrate of chromium may be made as follows:—17 lbs. of bichromate dissolved in 2 gallons of boiling water, and 27½ lbs. of nitric acid added, then, by small portions, 5½ lbs. of ordinary moist sugar, which has been previously dissolved in 1½ gallon of water. Upon cooling crystals of nitrate of potash will separate, and the clear liquor is the so-called nitrate of chromium.

WITZ gives the following modification, which may be called the aceto-nitrate of chromium:—In an earthenware vessel 6 lbs. of bichromate in coarse powder are dissolved in 9 lbs. of boiling water and half a gallon of nitric acid at 36° B.; and then a mixture of 23 ounces measure of white glycerine, marking 28° B., and 8½ lbs. by measure of acetic acid at 7° B. are added slowly at first, but afterwards sufficiently quickly to maintain the heat of the reaction at a high point, otherwise the decomposition is incomplete, and the liquid will remain brown coloured. When the decomposition is finished the liquor is transferred to a pan and boiled for a few minutes, until a portion viewed in a thin layer has a beautiful green colour; it is then transferred to the pot and left all night to cool. A considerable crystallization of saltpetre takes place, the clear liquor is decanted, and the crystals washed with a little cold water, and the whole mordant brought to a strength of about 30° B. The samples of colours appended to the paper of WITZ, in vol. i. of the *Bulletin of the Industrial Society of Rouen*, and obtained from this mordant with logwood, prussiate, berries, catechu, and alizarin, by steaming and soaping, are all excellent of their kind.

Other mordants than those enumerated are only employed for special styles and colours, and most of them will come under consideration when treating of the method of fixing mordants.

The only real mordants for general dyeing purposes in calico printing are the acetates of alumina and iron; these two compounds have been shown by CRUM and other chemists to possess most curious and exceptional properties, which have no doubt important bearings upon their application as mordants. CRUM showed that the acetate obtained by decomposing pure sulphate of alumina with acetate of lead was in all probability not a teracetate, resembling the sulphate in its constitution, but a mixture of biacetate of alumina with an atom of free acetic acid; upon quick but careful evaporation by regulated heat a residue of biacetate of alumina was obtained perfectly soluble in water. By boiling the acetate of alumina the whole of the alumina is deposited, combined with two-thirds of the acetic acid, the remaining third being left in the liquid. When the solution of the biacetate of alumina is exposed to heat for several days, it is seemingly split up into acetic acid and a modified alumina, which is soluble in water, but which is incapable of acting as a mordant; and when forced, as it were, to combine with colouring matters, it gives translucent lakes quite different from the dense opaque lakes which ordinary alumina gives with the same colouring matters. The peracetate of iron presents analogous properties, which, however, do not seem to extend to the protoacetate which is used by printers and dyers. These properties, and especially the existence of a modification of both alumina and iron, which do not act as mordants, may throw some light upon accidents in printing which from time to time occur and perplex the inexperienced colourist.

The practical precautions in printing acetate of alumina mordants are chiefly connected with the drying. If too quickly or too strongly heated in the drying, they are so much injured for dyeing good shades that no after care will succeed in obtaining full and saturated colours. This defect, which is less observed in strong reds and chocolates, is very conspicuous in light reds, and especially where the red liquor is for pale pinks, and reduced to a strength of less than 2° Tw. In such a case, if the temperature of the cloth reaches 212° Fahr. by actual contact with a metallic surface of that temperature, the deposition of the mordant becomes irregular, and only inferior results can be obtained in dyeing. To reduce the excessive sensitiveness of these dilute mordants, it is usual to employ a considerable excess of free acetic acid in the colour; and to provide against too much heating of the cloth, the steam chests are so arranged that the cloth shall not touch them, and sometimes the first range is further covered with cloth. In printing strongly acid alumina mordants care must be taken that the chests and rollers, which may be touched by the yet moist colours, are clean and free from iron rust or dust, which nearly always contains iron. It has happened in padding pink that a tinned iron roller at the top of a set of chests, the existence of which had been overlooked, was the cause of serious damage to the work by communicating iron to the cloth, which dyed up in specks of dark purple all over the piece. And on another occasion a lot of pad pinks were rendered inferior by the dust from the brushing down of an adjoining set of chests while the pads were being printed.

Iron mordants, even when very dilute, can be printed with much less risk of injury than alumina mordants; but as they are sometimes used so dilute as 1 of iron to 150 of water, it is evident that every attention must be paid to the state of the cloth, for very small causes would prevent the fixation of so feeble a solution. It is to guard against irregularities which might proceed from acid exhalations adhering to the cloth, or other resisting and destructive agents, that some of the best printers prepare all their cloth for pad purples with a preparation of chlorate of potash, either with or without addition of alkaline arsenite or arseniate.

Ageing.—After the printing and drying the calico is submitted to what is called "ageing."

The method of ageing has passed through many phases, which are probably not yet complete. It was at an early period called stoveing, because the pieces after printing were hung up in rooms highly heated by means of stoves, and apparently without any provision for keeping the air moist. The usual process in England, until within the last few years, was to hang the goods up in rooms freely exposed to the currents of external air, and without any provision for either heating or moistening the air. Ageing under these conditions was slow and irregular; a period of three days and nights was thought necessary for light styles of covered purples; heavier work, as garancins, were not unfrequently hung up for a week or more. In the usual moist atmosphere and temperate climate of these countries, the only inconvenience of this system was the length of time required to be certain of the ageing. In the case of dry winds and frosty weather the ageing was retarded, and sometimes to such an extent, that the printing was stopped for days together until the accumulated goods were disposed of. The Alsatian printers appear to have been the first to introduce closed ageing rooms with an artificially moistened atmosphere, and the idea of continuous ageing is due to John Thom of Birkacre, but then of Mayfield, who patented the machine in 1849; it was, however, not much used, except as a sulphuring machine, until Walter Crum of Thornliebank, some years later, worked out the process, and showed the conditions necessary to success.

The ageing machine, as usually constructed, is a room provided with a series of rollers above and below, by means of which the cloth to be aged travels through, and is exposed to a warm and moist atmosphere. The form and dimensions of this room must vary according to the conveniences of the works; but it must be of such dimensions that a given portion of a piece shall be from fifteen to twenty-five minutes in traversing the room, and that the rate of delivery shall be rapid enough to meet the quantity of goods printed. Fig. 16 is a sectional elevation of an ageing machine, and Fig. 17 is a plan of an ageing machine.

Fig. 16.

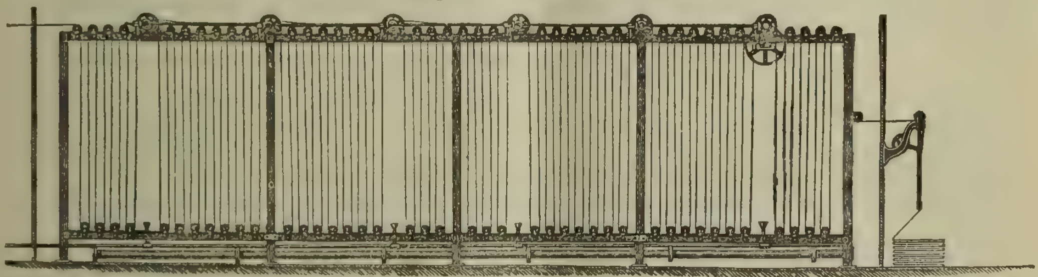
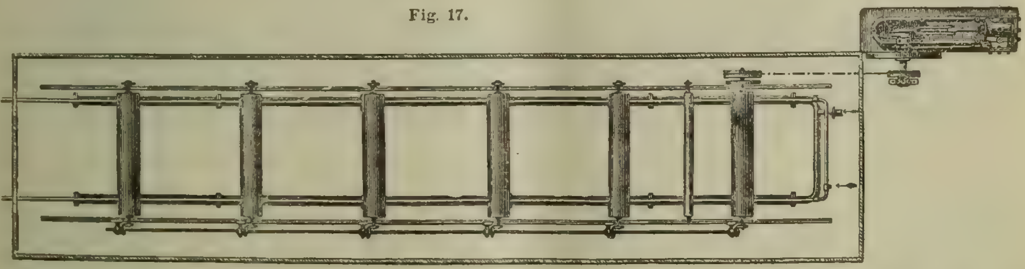


Fig. 17.



The temperature of the air, and its degree of humidity, may vary within considerable limits without injury to the work; but the higher the temperature, and the more saturated the air, the more effective is the ageing. In practice, however, it is not found convenient to go higher than 100° Fahr. for the dry bulb thermometer; and if the wet bulb be at say 94° or 95°, the atmosphere is in a favourable state for rapid ageing. Temperatures of 20° lower than these may also be found suitable for lighter work, or even 20° or 30° higher may be used with advantage. Upon this point the local position of the machine is the only true guide. If in a warm place, as over the drying room of the machines, and surrounded by warm air, a higher temperature and a closer saturation can be employed; but in such situations the difficulty will be found to consist in keeping the atmosphere sufficiently moist. In other localities where the external atmosphere is not heated, it will be found necessary to work at comparatively low temperatures, on account of the danger of drops of water condensed from the steam either inside or outside the machine. The external indications of the machine working in a suitably warm and moist atmosphere, are in the soft feeling of the cloth as it is delivered at the exit, the amount of acetic acid evolved, and the development of colour as seen in catechu brown. An experienced foreman can tell very well upon putting his face inside the machine whether it is in good working order or not; the condensation of moisture upon the skin, and the feel of the air on the lungs, are sufficient indications for him.

After having passed through the ageing machine, the pieces are bundled up and placed in a room kept warm and moist, and are left there for a night or longer before going on to the dye house, or before being passed a second time through the ageing machine.

The action of the warm and moist air upon the printed cloth, and upon the mordants, is in the first place to restore the water naturally existing in calico, which has been expelled by drying; then to bring the thickening into what may be called a normal state of moisture from the hard dried state in which it left the drying part of the printing machine; and then to commence a chemical action upon the mordants, which is partly an oxidation, and partly a decomposition. That there is oxidation direct or indirect (even from the air or from the constituents of the colour) is visible upon comparing cloth printed with catechu brown, iron buff, or aniline black, before and after passing through the machine; that there is decomposition of the acetates is apparent from the torrents of acetic acid liberated from heavy mordants of red or chocolate, which make it impossible to support the atmosphere at the upper part of the ageing machine. But it is highly probable that the useful action of the ageing machine is nearly all confined to giving a proper amount of moisture to the dried cloth and colours. It would not be safe to send out anything heavy direct from the ageing machine into the dye house; it is found beneficial in all cases, and necessary in some, to leave the printed cloth, as before mentioned, some hours longer in a proper atmosphere. CRUM held that the bundling up of the cloth did not interfere with the oxidation supposed to be necessary, for that the power of diffusion of gases was sufficient to maintain the necessary circulation, even when the cloth was pretty tightly wrapped up. The experience of practical men will hardly support this view, for in the rare cases where the action of oxidation is at all visible, it is evident that it is much more apparent on the exterior of the bundles and edges of the pieces. In such a colour as catechu brown, which may be said to carry a good deal of its required oxygen in the nitrate of copper, it is not very perceptible, except in heavy masses; it is plainly seen in strong iron buffs, or most of all in aniline black. If ageing was chiefly or entirely a matter of oxidation or of chemical action, the ageing machine would be a failure, for there is very little oxidation, and very little evolution of acetic acid, when the pieces have left the ageing machine. But it is supposed that the most essential action of ageing consists in putting the thickening into a soft or plastic state, and keeping it so for such a length of time as will enable the mordant to get into intimate contact with the fibre.

Although the ageing machine is very generally employed, still ageing by hanging is much practised, and found to be very safe, and sometimes more economical than the machine. For this purpose an artificially warmed and moistened atmosphere is nearly universally employed; to obtain a regular distribution of moistened air in large rooms is not difficult by means of jets of steam, but in confined spaces it requires some care.

The following is a simple and effective injection method:—A wooden pipe, about 9 inches square inside, and as long as the room, was laid down on the floor, or suspended against the wall; it was bored at intervals of a foot on one of its sides with holes an inch in diameter; one end of the pipe was closed, and a steam jet from a nozzle of one-eighth of an inch or less introduced at the open end, blowing in the direction of the length of the wooden pipe. The steam jet drew in a vast volume of air, which became thoroughly mixed with the steam, and was expelled with force from the lateral openings, which were so directed as not to make the current impinge upon the goods, but strike against the floor or ceiling. By having the open end of the wooden pipe outside the room fresh air and ventilation were secured, and by a large steam pipe inside the tube, or so placed that the air and steam passed over it, the necessary temperature was obtained. (O'NEILL.)

The temperature and degree of moisture in ageing rooms varies very much in different places. It is usual to keep the temperature so low that operatives can work in it without inconvenience; another method, which was much followed on the Continent, and with good results, consisted in filling the room with goods, say a thousand pieces or more, then closing it and turning on the steam both in the warming pipes and moistening jets, until the temperature reached 110° or 120° Fahr., and the air nearly saturated with moisture. The writer has been in such rooms for the few minutes it was possible to endure the temperature, and felt the pieces, which were quite soft, and seemed to threaten the running of the colours, which, however, he was told never happened. When the heating has gone on for some hours the jets of steam are turned off, the heating pipes being kept on, and after a while the room opened and the goods taken down.

Ageing machines have been constructed to work at temperatures of 150° to 170° Fahr., and have been found to answer very well for garancin styles, but generally to finish the ageing after the pieces had been hung a day or two. To keep up this high temperature, and to prevent drops of water, it is necessary to have the ceiling of such a machine composed of steam chests; the time of exposure may be reduced to three or four minutes, and consequently smaller machines are made than the usual low temperature machines.

The use of chemical gases to assist ageing has given no good practical results. In those cases where ammonia gas is employed the action cannot be properly compared with ageing; it is more correctly a fixing or a neutralizing action, and generally follows the ageing correctly so called.

Ageing liquors made from chlorate of potash and alkaline arsenites have been used to assist the fixing of black and chocolate mordants; they are mixed with the colour, and are somewhat uncertain and capricious in their action.

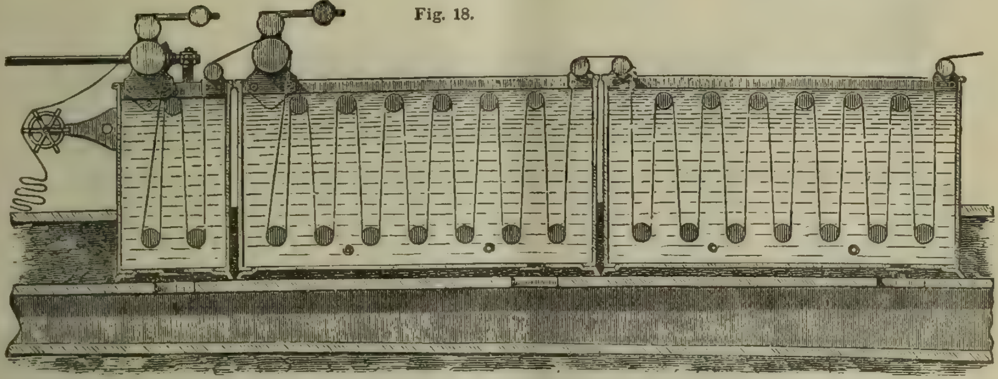
Dunging and Fixing.—The ageing is followed by the process called dunging, cleansing, or fixing.

The dunging process is carried out in quadrangular vessels preferably made of cast iron, which are furnished with rollers above and below, some of which are driven by power. It is usual to have a series of three vessels or dunging dollies, and at the end of each a wince or draw rollers driven by power to draw the pieces through the liquid, the pieces having been previously sewn together.

Fig. 18 shows two of the three cisterns or dollies of the first dunging arrangement; the cloth proceeds from right to left, and is made finally to pass through a small cistern of cold water, and is then taken off by the wince either to go on directly to the second dunging or to be washed.

The substance which has been used from time immemorial in this process is cow dung, and although several effective substitutes have been found it is still much used, and for some purposes preferred by intelligent dyers. It is only a matter of conjecture as to what portion of the cow dung acts usefully, and what the action is upon the mordants; this excrement is of a very complex nature, and chemists have not succeeded in their attempts to define the constituents upon which its efficacy as a cleansing or fixing agent depend. Practically it is found that if the pieces after ageing were passed into unmixed water, warm or cold, the colours after dyeing would not be full or saturated, and the whites would be very bad after a few pieces had been passed through the vessel of hot or cold water; both these effects being due to the fact that no practicable agency can fix the whole of the mordants printed on calico, that on passing through water the unfixed mordant dissolves in it, and that after a while the water is converted into a dilute mordant, which fixes more or less completely over the whole surface, spoiling both whites and colours. If thoroughly aged cloth be washed off after printing in a running stream, where the water in contact with the cloth is perpetually renewed, the inconveniences described above are reduced to a minimum, and fair work can be produced; so that it might be said that the use of cow dung and substitutes is to enable the dyer to wash off a great quantity of mordanted cloth in a limited quantity of water without injuring the colours.

Fig. 18.



Supposing that cow dung is the substance used, the procedure is as follows: the dunging cistern is filled with water to the height of the top rollers, the steam is turned on, and while the water is heating a quantity of cow dung is stirred up in it, this quantity varies according to the nature of the dung, and the styles to be dunged, from 1 to 5 per cent. of the quantity of water. The temperature of dunging is regulated by the styles; light styles and light colours require only a low temperature, say about 140° Fahr. Alumina mordants for pink, and especially for bark yellows, should be dunged at as low a temperature as will suffice to dissolve out the thickening; for yellows, in the neutral style, to be dyed in bark, and for red liquor pinks from madder, where there is not much colour, washing off in cold water in a stream without dunging is the best preparation for dyeing. For dark styles printed with paste colours, as the usual garancin styles, and for styles containing much acid, a high temperature, say 180° Fahr., is required; and it is useful, and may be necessary, to add a few pounds of ground chalk to each of the dunging cisterns, especially for patterns with acid in. This refers to the first dunging, into which the pieces go at full width, and which occupies from one to three minutes. The dung and chalk are kept up to the first strength by additions made at stated intervals of time, or according to the number of pieces passed through.

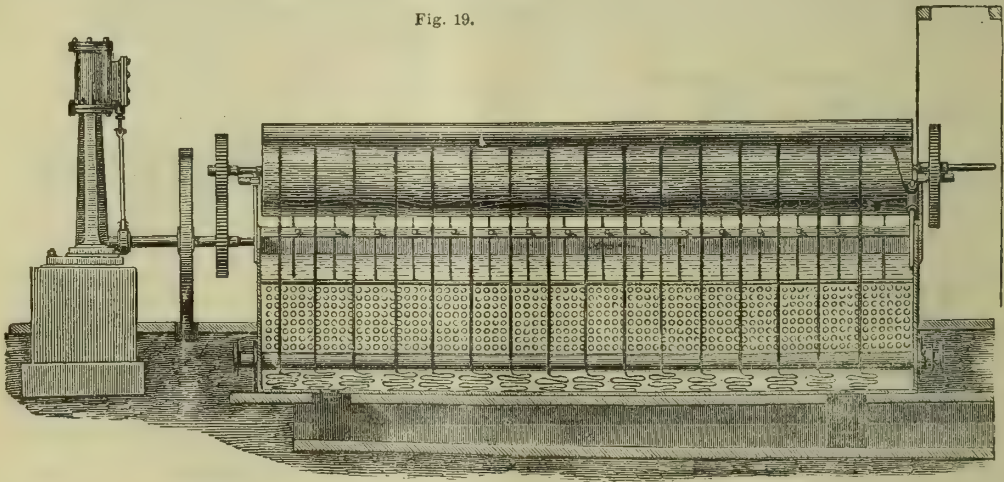
Fig. 19 shows one of the second dunging becks, of which there may be three or more side by side; the cloth no longer at full width, but as dyers say in the rope, passes in a spiral manner continuously and without interruption through the whole series, and is then washed.

Dyers are divided in opinion as to whether the goods should be washed between the first and second dunging or not. If the washing machine be conveniently placed, this does not involve much trouble or expense, and it keeps the second dung becks clean for a longer time; but in the majority of styles there seems to be no necessity for it, and it is better even that the pieces from the first dunging should not be cooled by passing through cold water, but that they should go straight on, hot as they are, into the second dunging.

The effect of the first dunging is to dissolve off the more soluble matters in the colours or mordants. Most of the unfixed oxides are removed, and held in such a state of solution or suspension in the dung liquor as not to be hurtful to other mordants and the whites; but the action is incomplete, and the greater portion of the starch or flour thickening is not dissolved off, and a good deal of unfixed mordant is still mechanically adhering by means of this unremoved thickening. The object of the second dunging is to complete the cleansing of the cloth from these matters. The temperature of the second dunging must also vary with the styles. Generally paste thickenings must have a high temperature, but not exceeding 170° Fahr.; iron mordants and chocolate mordants, containing a large proportion of iron, seem to be uninjured even by an excessive amount of dunging. It is not so with alumina mordants, which are seriously affected if the strength of dung, temperature, or time, pass a certain given limit, and these styles demand a close attention on the part of the dyer.

The main object of dunging, it is seen, is to remove the thickening matters employed by the colour-mixer; with them the unfixed mordant comes away, and the cloth goes into the dye beck clean, without any loose mordants which may be detached in the dyeing process, and cause trouble and irregularity in the dye beck. The complete removal of some paste thickenings is nearly impossible. They may be repeatedly dunged and washed, and upon drying a fent it is found still stiff with thickening, and if tested by iodine in the laboratory the presence of starch is readily detected. If inferior work is the consequence the dyer cannot be justly blamed; the fault is either in the quality of the thickening used, or in a baking of the prints on the steam chests of the drying machine. In case of such a difficulty, the experienced dyer will give the longest dunging and the best washings that the styles will support and if possible leave the goods wet all night, and wash again before entering into the dye, and so mitigate as much as possible the inferiority which is inevitable. For in the course of the two hours time the goods are running, say in garancin, alizarin, or madder, the obstinate thickening is gradually giving way and being dissolved in the beck. The mordant which it has held becomes diffused in the dye liquor, and absorbs the colouring element which ought to be reserved solely for the design, and unless an excess of colouring matter has been used the goods are underdyed; the beck liquor, which ought to be clear, is highly coloured and opaque, and first-class work cannot be obtained. Twenty minutes to half an hour is the longest time that should be required in the second dunging, and this is followed by two, three, or four passages through the washing machine. The practical test of a well-dunged cloth is to take an end and rub or beat it in the hand, and squeeze out the water. If the water comes clean, the presumption is that the cloth is well dunged and washed. The disappearance of the sightening is not a reliable guide. In some cases of dunging with substitutes the logwood sightening of red liquor mordants dissolves out, and dyes the whole piece of a light slate colour; but no harm was ever known to follow this appearance.

Fig. 19.



There have been a great number of chemical preparations used as substitutes for cow dung, but only two are of sufficient importance to require mentioning, and these are the arseniate and the silicate of soda.

The solution of arseniate of soda, made at about 28° Tw., may be used in proportions of 1 part to 100 of water for the strongest dunging liquor, and 1 to 300 of water for the weakest, adding chalk for most styles. When of good quality the arseniate is a perfect substitute for cow dung, and much more reliable and more pleasant to work with. The writer was at one time so placed that cow dung could not be got without great expense and difficulty, and for three years employed nothing but arseniate of soda, and with perfectly satisfactory results. The only point in which it yielded to cow dung seemed to be in the finer shades of madder pink, which after experience showed could be obtained of a purer and fuller tone with cow dung. Alumina mordants are, so to speak, backened by the arseniate, and if a piece containing red be dunged in cow's dung, and another piece of the same printing, but dunged in arseniate, be dyed together, the latter is found to be much slower in absorbing colour, requires a higher temperature, and is never quite so fully saturated as the cow-dunged sample. For iron mordants and for chocolates the arseniate is at least not inferior to cow dung. Many dyers who use arseniate consider they could not succeed with it unless a certain mixture of cow dung was mixed in the cisterns and becks along with it. Such a mixture, although not injurious, is quite unnecessary with good thickenings. It may serve a useful purpose in helping to scour off thickenings by friction of its insoluble matters, but as a chemical agent it is entirely eclipsed by the arseniate.

Arseniate of soda is of variable quality, and some qualities are quite unfit for dunging. The binarseniate is acid, and should be neutralized before using; the dyer generally uses chalk; caustic soda would be preferable if there were no risk of using an excess. The ordinary arseniate is sometimes sent out strongly alkaline; this is a great fault, and may lead to the damage of goods. A case came under the writer's observation, when fifty or sixty pieces of pinks were utterly spoiled by using an alkaline arseniate. The lightest pink was dissolved almost completely out, and the others seriously injured and of a very bad shade, and this although the temperature of the dunging was not higher than 120° Fahr. Upon discovery of the cause the alkaline arseniate was rectified by adding sulphuric acid, and then gave the usual good results.

The silicate of soda, though not a favourite in Great Britain, may be said to be the chief dung substitute employed on the Continent, and it is used successfully for all styles. It is made of very good quality, quite without free alkali, and is safe for the most delicate pinks, as well as purples and heavier colours. Common makes of silicate contain almost invariably free caustic or carbonate of soda, which act upon alumina mordants very powerfully and destructively, and cannot be safely used as dung substitutes.

In treating of cow dung nothing was said upon the fixing properties which it is supposed to possess. If it does actually enjoy the power of fixing or precipitating any unfixed mordant upon the fibre, it is only to a very small extent. But this is not the case with the two substitutes mentioned, which can be made into real fixing agents; that is, they can decompose such salts as acetate of iron or sulphate of alumina, with abstraction of their acids and precipitation of their bases, combined with the arsenic and silicic acids. The degree of dilution in which these salts are employed as dung substitutes renders it very doubtful whether they do exercise any fixing or precipitation of oxide upon the fibre or not; probably all their action is confined to making insoluble, and therefore inert, all the possible soluble oxides remaining after ageing. It is thought by many that that portion of the salts of iron or alumina which has not been fixed by a proper ageing had better not be fixed in the dunging process, which should be limited to a cleansing action.

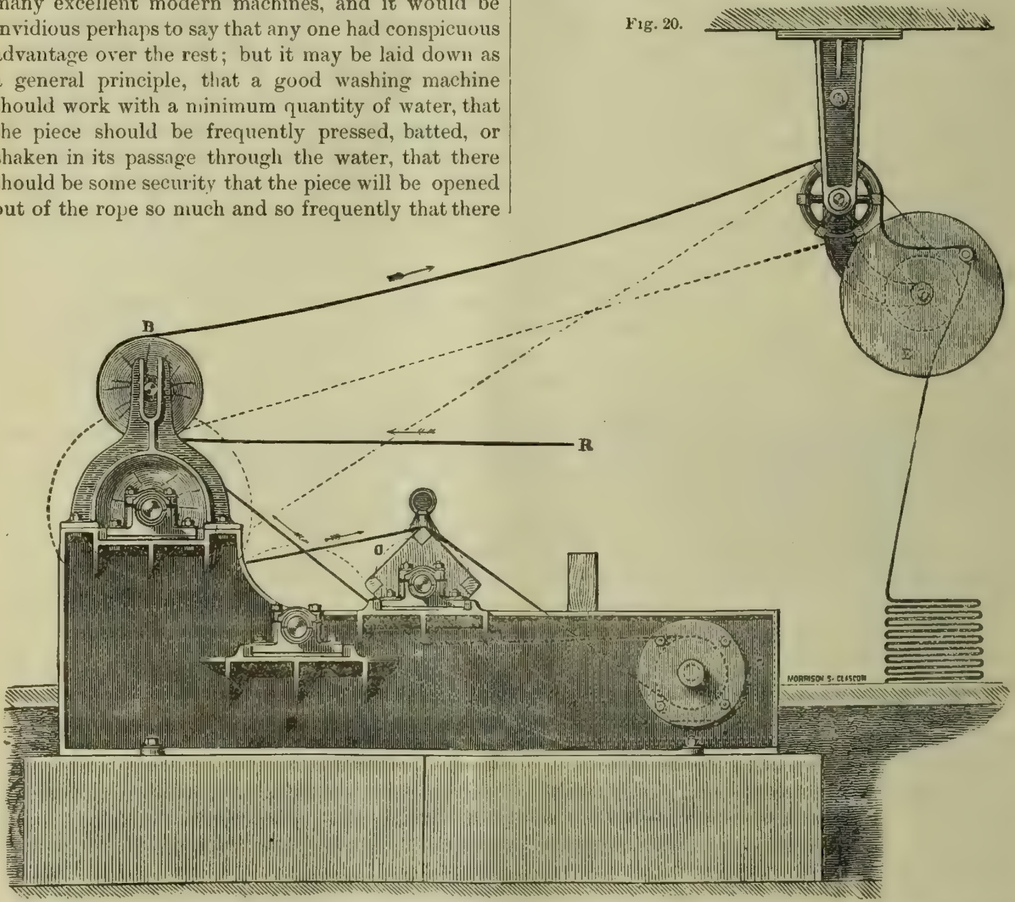
Fixing.—Here it is proper to notice various operations of real fixing of mordants and colours, which are carried on in the same or similar apparatus as dunging, and at the same stage of the progress of the piece; such are fixing lead for orange, iron buffs, aniline blacks, and generally what are often called soda colours and chromed shades. Without entering into details of the various styles a description of the fixing agents would hardly be intelligible, the object generally being to precipitate the mordanting salt or colouring oxide upon the cloth by decomposing the salt with some powerful agent. For example, to obtain a chrome orange a thickened solution of acetate and nitrate of lead is printed, and may be submitted to the ageing process, but neither of these lead salts undergo any chemical change by ageing, nor show any affinity for the fibre, and would be almost entirely washed away if passed through any of the dunging solutions or substitutes. The cloth must be passed into a fixing liquor, which may be either a strong and hot solution of sulphate of soda or a cold and moderately strong mixture of sulphuric acid with water; the soluble lead salts are completely changed into the insoluble sulphate, which adheres to the cloth and is a real mordant, to be dyed up by a real colouring matter, the chromic acid in bichromate of potash. In the case of iron buff, which is usually a mixture of acetate and sulphate of iron, a portion of the iron is fixed by ageing and a portion not. To complete the fixing the cloth is passed through lime and water, through solution of soda ash, or through dilute caustic soda, and the depth of shade obtained is proportioned to the strength and activity of the fixing solution: so with other metallic colours, as manganese, chromium, &c. This is often called raising the colour, and is applied with many modifications to the various classes of colours requiring it; and, as before stated, the operation is carried out exactly like the first dunging of the usual dyed styles.

Washing.—Washing after dunging is a very important step which is often neglected, to the great injury of the colours. In dunging with cow dung, the absence of visible remains of the dung on the piece was taken as a test of sufficient washing; but with the substitutes there is no similar test, and the dyer must use other means of ascertaining whether justice has been done in this respect. Defective washing in modern washing machines may be generally traced either to want of a sufficient supply of water, or to the cloth being so tight that some parts of it never get into free contact with the water.

Washing in earlier times, and even yet in some places, was effected in running streams, and various machines have been devised to supplant hand labour in drawing the goods through the water, and giving them such a degree of pressure and friction as will best facilitate the removal of adhering matters. But most dyers have to work with a limited supply of water. Of all the washing machines ever used, probably none excelled the dash wheel for efficiency, and it was the principal machine in use up to about 1856, when it began to yield to more rapid methods of washing. The drawback to the dash wheel was its slowness, the large quantity of water it required, and the great power it took to drive. There are many excellent modern machines, and it would be invidious perhaps to say that any one had conspicuous advantage over the rest; but it may be laid down as a general principle, that a good washing machine should work with a minimum quantity of water, that the piece should be frequently pressed, batted, or shaken in its passage through the water, that there should be some security that the piece will be opened out of the rope so much and so frequently that there is reasonable certainty that every part of it will be exposed to the washing action, and that the supply of water should be so arranged that the clean water comes in where the piece goes out, and that in the body of the machine the dirty water shall not mix with the cleaner. In addition to these practical requirements, it must be of such a construction as not to be liable to strain or tear the pieces, and not require too much power to drive it.

Figs. 20 and 21 show the end and sectional elevation of a washing machine by Gadd of Manchester, which is well suited for dyehouse requirements. The cloth enters at R between the rollers, and travels in the direction of the arrow to *a*, where it passes over the square beater, and under the water supply from a perforated pipe, thence round a roller working under water, and back by the lower part of the square beater between the rollers A and C, and so spirally progressing until it is delivered by B and D, the latter being a pressure bowl to the plaiter down, E. The action of the square beater is to dash the cloth quickly and forcibly against the surface of the water, to keep it open, and by this mechanical movement detach matters which ought to be removed.

Fig. 20.



Dyeing Apparatus.—The cloth is now supposed to be ready for dyeing, it may be in madder, artificial alizarin, logwood, garancin, or other dyestuff, for the general procedure is the same in all cases.

The primitive system of dyeing was in copper pans heated by naked fire, and provided with a roller and winch at the top for keeping the goods in movement. From this old method, now only used in remote places and for some kinds of woollen dyeing, there have come down some trade terms yet heard in dyehouses—a dyer was a copper man, the process of dyeing was coppering, and stains which became visible in dyeing were copper stains. The application of jets of steam to heat the dyeing vessel instead of fire was made in England early in the present century, and the use of wooden dye becks soon followed, which could be constructed of a more convenient shape than copper pans, and were much less expensive. The first wooden dye becks were, however, nothing more than oblong tubs, strongly made and coopered, with a wince sometimes for hand turning, which was gradually improved into driving by power. Perhaps the next improvement was in making the beck ends of cast iron, and soon afterwards the whole dye beck was made in a single casting of iron, and that material is now preferred. Lately attempts have been made to introduce dye becks of double cased copper, so that the dye liquid may be heated like the contents of a colour pan, without coming into contact with the steam, and so avoid the inconveniences which may arise from the impurity of the steam, or the increase of bulk due to its condensation in the dye beck. This principle of a dye beck, which had been long previously employed for yarns, was expected to have great advantages in madder dyeing, and generally in all cases of dyeing where the proper extraction or transfer of the colouring matter required a long continued heating of from two to three hours; for it was ingeniously argued that as the dyeing progressed, the amount of colouring matter diminished, and the volume of water increased, making it more and more difficult for the mordants to exhaust the dyestuff, whereas, in a rational system of dyeing, the volume of water should diminish in a ratio approximative to the diminishing quantity of colouring matter which remained to be extracted. The writer confesses he was very much disappointed after having advised a set of four of these becks to be put up at a very heavy cost, that he could not get the slightest advantage in the way of economizing dyestuff by their use. Hundreds of comparative trials were made with negative results, not only with madder, garancin, and alizarin, but also with logwood and bark; and it seemed to be clearly demonstrated that heating with naked steam was the best when proper arrangements of steam pipes were employed, and care taken that condensed water from the pipes did not enter the dye beck. The amount of steam required to heat one of the double-bottomed becks not clothed with any non-conducting substance was immensely more than was necessary for the common becks. Pieces run on these becks remarkably smoothly without any mid-feather, until the beck is brought near the boil, when the absence of rail or roller at the bottom is felt.

Fig. 21.

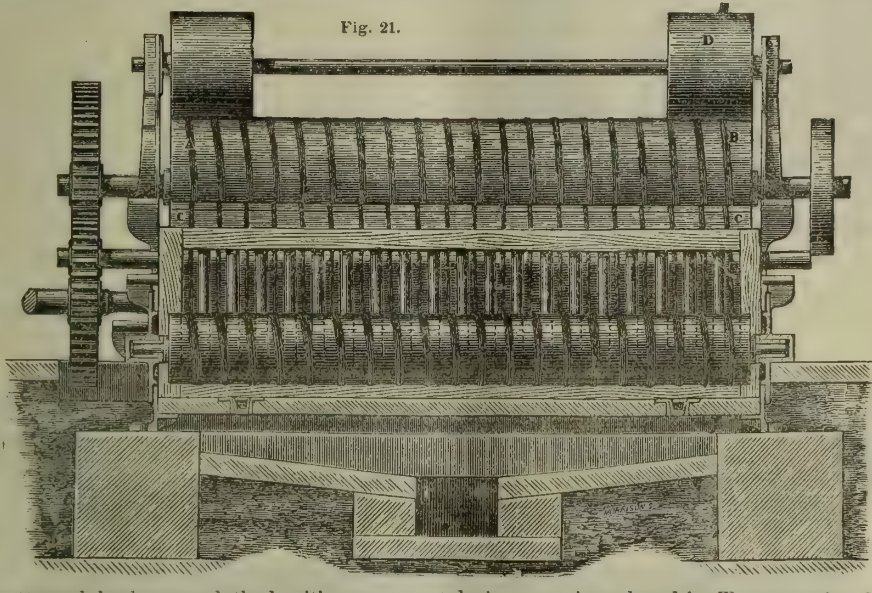
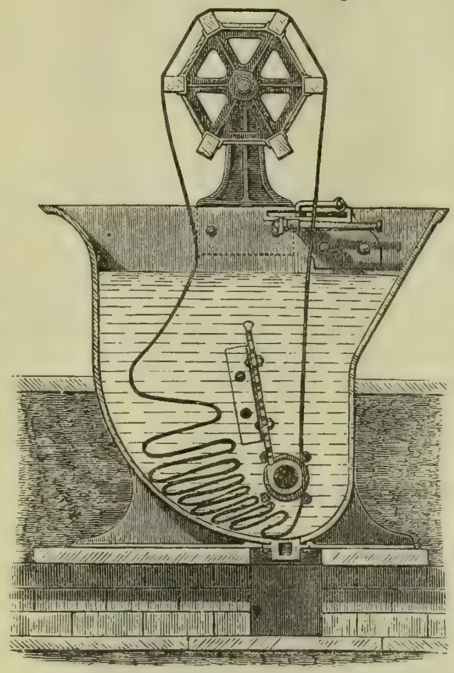


Fig. 22 shows the end section of a cast-iron dye beck for madder dyeing, heated by naked steam supplied by perforations in a pipe extending the whole length of the beck. Fig. 23 shows a front sectional elevation of a dye beck on the continuous system, in which the pieces are all sewn together and run spirally.

The shape of the dye beck is devised so as to permit the dyeing of the pieces with the smallest possible quantity of liquid, which is important, in order to permit the mordants to exercise their attractive powers, and to avoid waste of steam, or heat up an unnecessary quantity of water. The system of spiral dyeing, or as it is sometimes called continuous dyeing, was introduced by Thompson in 1852. The pieces, sewn in one length, are entered at one end of the beck, and the slack being divided as equally as possible, the piece is gradually advanced towards the other end by means of the peg rails in a screw-like spiral progression, and the two extremities of the length of cloth being joined, the piece, when it has travelled the whole length of the beck, is drawn to the entering end over rollers guided by pot eyes, and repeats the same course. Thompson's plan included a cylindrical wince and a top-pressing roller, much the same as the modern continuous soap becks. It did not come into general use, because the operative dyers objected to its difficult management, and it was further believed that the smooth wince and smooth roller pressed the dyestuff into the cloth in a manner which was injurious to both colours and whites. At the present time the top pressing roller is dispensed with, and substituted by a pulley at each end of the wince, which enables the wince to be made of the usual angular form, avoiding the constant squeezing of the piece and the necessity of a stripping roller, which all round winces require in slack dyeing.

Fig. 22.

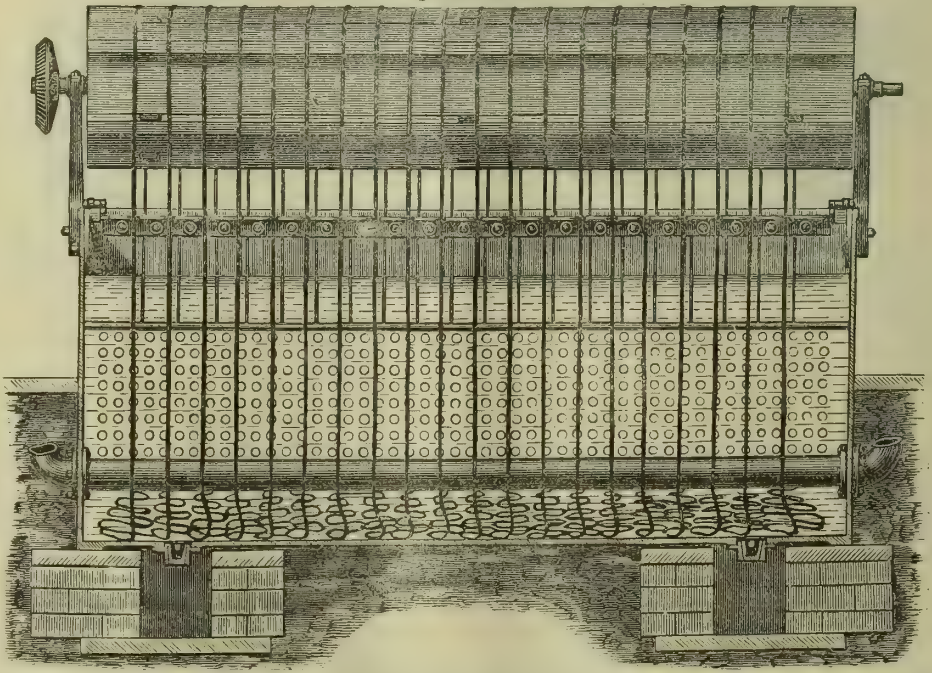


The spiral system insures regularity in the dyeing in so far as it secures uniformity of heating; in dye becks of an inferior construction there is a great liability of one end being much hotter than another, or of both ends being hotter than the middle, and the pieces which occupy these places are, of course, unequally dyed. In the spiral system, even if this defect exists, it cannot injure the work, because the pieces have an equal exposure to the liquid in every part of the beck, and must in this respect be all alike.

Since the introduction of concentrated extracts of madder and artificial alizarin, attempts have been made to dye the old madder styles in an apparatus analogous to the dunging dolly, sending the pieces through in the open state, and employing a large excess of colouring matter. By these means the time of dyeing may be reduced from two hours down to five minutes; but it does not appear that this plan is economically practicable, on account of injury and waste of the colouring matter, which more than counterbalance the saving in time.

The most ordinary method of dyeing for calico printing is to enter the pieces into the dye beck, either in a number of single lengths or spirally, and while they are running over the wince the dyestuff is added to the water; the steam is turned gradually on, and the heating carried on in a regular progressive manner without stopping, until it is supposed the pieces are sufficiently dyed, or the dyestuff exhausted. The time and temperature required to accomplish this vary for different styles, and for different dyestuffs.

Fig. 23.



Madder Dyeing.—In describing dyeing for calico printing, it was formerly necessary to consider it specially with regard to madder dyeing, that branch being far more important than all others, and the one most difficult and complicated. But the last five years have witnessed the introduction and extension of the application of artificial alizarine, which has so far supplanted madder, that establishments which formerly consumed two tons of madder roots per day in the dye house, have now either entirely ceased to use it or employ it in very few cases of dyeing. All the history and analyses of the proximate principles of madder root, which have occupied many celebrated chemists, as SCHUNCK, DEBUS, ROCHLEDER, HIGGINS, KUHLMANN, STRECKER, and others, and which were supposed to be in some way or other connected with its colouring matter, and to influence its application in the arts, have lost their interest to the technical man. Rubian, erythrozym, and xanthin, with a score of other bodies, may or may not exist in this or that sample of madder root, or may or not be the cause of colouring matter in the madder; that is now a question of remote scientific interest. What is certain is that anthracene can be transformed into alizarin, and the successive steps of the transformation can be followed as clearly, as easily, and as certainly, as if we were going through a simple equation in algebra; and we come across none of the twenty or thirty subsidiary madder products which ingenious chemists formerly tried to connect together by linking them with alizarin.

The revolution effected by the introduction of artificial alizarin has been much more complete upon the Continent than in this country. Here the dye house is still occupied, though the dyeing product be an artificially made fluid or paste, and not the natural root of a plant; but abroad the madder dye house has no more dyeing to do, the colours are all applied topically and steamed, and there only remains washing and soaping to be completed after the old system. Whether madder dyeing is to be succeeded by alizarin dyeing as carried out in England, or by making a topical colour of it and fixing by steaming as on the Continent, is a question that cannot yet be answered, and the solution of which will in great measure depend upon economical considerations This much is certain, however, that the Continental colourists have already arrived at a degree of perfection in the topical application of these colours in plate pinks, pad pinks, dark reds, lilac shirtings, and covered purples, which is scarcely credited by the English printer, and with which he can barely compete either in price or quality.

In the present state of affairs the purpose of this article will be best fulfilled by treating here of madder and alizarin colours together, whether the latter are obtained by dyeing or by steaming, for it will be found that the principles involved, and in fact many of the treatments, are identical or very similar.

Madder styles may require from a ½ lb. to 7 lbs. or 8 lbs of the root for the average piece, having from 6 lbs. to 7 lbs. weight of cotton; the smaller quantity is for the lighter styles of purple, with very little colour on the design, and the heavier for pink designs well covered, or pad pinks. There are various qualities of madder possessing different amounts of colouring matter. The French, Dutch, and Turkey madders do not differ greatly in tinctorial power, though having some distinctive properties; the Derbent or Caucasian madder is nearly twice as strong as the average quality of French, but it is rarely employed in this country. Derived from madder we have also garancin, garanceux, the so-called commercial alizarin, and lastly, the flowers of madder. They have all the same colouring principle, and their history and chemical properties are given in another place. They are mentioned now to state that the process of dyeing is the same for all; the subsequent treatments differ, but their behaviour in the dye beck is subject to the same general rules, and requires the same precautions and treatments. The artificial alizarin may also be included in the list.

The amount of water employed in the dye beck is to be the smallest quantity necessary for the proper circulation of the calico; there must be sufficient for the goods to move easily, and to hold the dyestuff in suspension, without any approach to thickness. An excess of water is against the dyeing, and to be avoided, because no water is so pure as not to contain some salts which are of an injurious tendency, and great dilution wastes colouring matter. In those styles which require more than 5 lbs. of madder per piece it is best to dye at twice, on account of the gelatinous state the liquor is likely to assume when there is too much madder in it; taking about three-fifths of the required quantity of madder for the first dyeing and the remainder for the second. The results in heavy reds and pinks is more regular than if the dyeing be attempted at one operation.

The heating of the beck is to be as regular as possible, never letting the temperature descend from a point once reached. Allusion has been made to the unequal heating of becks; this is owing to a bad arrangement of the steam pipes, or to the holes from which the steam issues in the beck being too large; irregularities may also happen from the becks not being set level in their foundations, and one end being deeper in water than the other.

The temperature for madder dyeing may be quickly raised to about 120° Fahr., and then gradually advanced to the temperature determined upon. For the usual run of work the time is two hours, and the highest temperature about 180° to 200°; for fine reds and pinks it is not desirable to go higher than 170°, and the time may be increased to three hours; for fine purples the temperature should not pass 180°. Garancin styles, with chocolate red and black, may be advantageously heated to the boiling point for the last half hour.

The points that the dyer has to attend to in the running of the pieces are merely mechanical, and the only accidents proper to the dye beck are torn pieces and turned threads, which may result from a stoppage of the circulation of the pieces, and the dragging of the wince against the stationary cloth. Turned threads, or as they are sometimes called "screeves," show most plainly upon padded or close covered styles, the printed side of the warp having been so pulled and twisted as to turn it out of its position on the cloth, and to show the back or unprinted side on the face. This fault may happen after dyeing, in soaping, or even in washing, and is not necessarily due to the dyer's negligence. If pieces stand in the beck through any stoppage while the steam is blowing freely against the cloth, light places will often be observed. Pieces near the side of the beck are sometimes badly stained; this may be owing to impurities brought in with the steam. The presence of much condensed water in the steam pipes, which finds its way into the dye beck, is frequently a cause of inferior results in madder dyeing.

The dyeing being completed, the pieces are taken out either into a waggon to go to the washing machine, or placed upon a stillage from which the washing machine can draw them; or as was formerly usual, they are taken direct from the dye beck into a pit of cold water, where they are turned once or twice by the wince, to rinse and cool them, and thence to the washing machine.

The washing after dyeing may be effected in the same machine as was used after dunging. It is advisable to wash well, even for work which has to be soaped; and for garancin and similar styles which are not submitted to the soaping process, the washing must be of a very complete nature, and may require three or more passages through the washing machine. When the washing is completed, the cloth ought not to give any coloured liquor when a portion is rubbed in the hands, and the water wrung out.

For some kinds of work no more dye-house treatment is required, but for a good class of work even in garancins, alizarins, and logwood blacks, it is usual to pass the pieces through hot water and give another light wash. This is found beneficial, because the best washing in cold water leaves a hurtful amount of loose colouring matters or dye wood embedded in the fibres, which is either dissolved out or loosened by hot water and a slight subsequent washing.

All styles of madder and artificial alizarin work require further treatments in order to clear the white parts of the design, and to brighten and improve the colour.

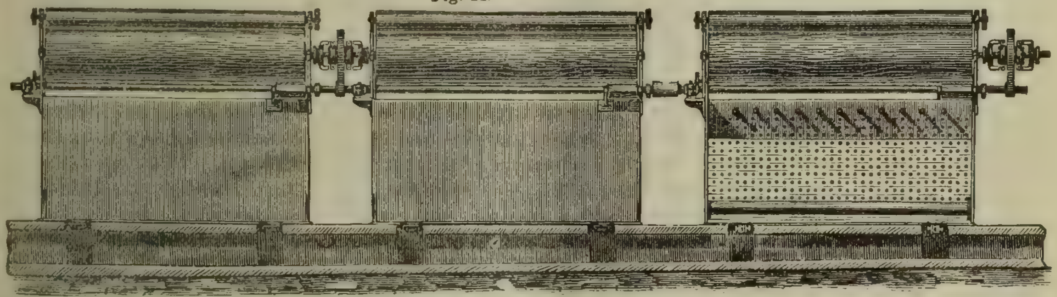
Madder purples are now usually submitted in the first place to a passage through cold and very dilute solution of bleaching powder, so weak that it can scarcely be perceived by tasting. This passage may last from five to ten minutes, and is best done in a beck working on the spiral system, the cloth entering at one end and going through to the other, and then passed through a beck of clean water, which gives a sufficient amount of washing.

The soaping of madder styles is a very important operation, for upon it depends in a high degree the beauty and permanency of the colour, and the brightness of the white. The kind of soap to be used is one which should not contain anything but fatty matter, alkali, and water; a certain percentage of rosin is not disadvantageous, but a soap free from rosin is on the whole to be preferred, as that alone can be relied upon for the best quality of work. There are a great variety of soaps in use by printers, which show considerable differences of composition in analysis even of those kinds which are known to be good. It does not seem to be important what kind of fatty matter is employed, so that the fat is well combined with the alkali; and upon the whole, it appears that a slight excess of alkali, above that required to form a neutral soap, is an advantage. The pure curd soaps do not work well nor economically in average qualities of water; to use a dyer's term, they break too easily, and do not lather sufficiently. The best printers prefer a palm oil soap made from the unbleached oil, and entirely free from rosin or silicate of soda, and with an amount of alkali very slightly over the amount indicated by theory. But very good soaps are made from cheap fats, as bone tallow, oleine, and vegetable oils, and they have generally an advantage in being of a soft nature, and readily soluble in water. Many of the varieties of printers' soaps are sold in a highly hydrated state, and containing saline matters of an entirely useless character, and though offered at a low price, prove in practice less economical than higher priced and purer qualities. The action of soap upon madder work may be considered to be of two different kinds—there is the scouring and cleansing action to remove the impurities and the false dye principles which have fixed upon the mordants, and which hide or disguise the true colour; for this probably a very inferior quality of soap might suffice: the second action is of a more obscure and perhaps questionable nature; it consists in the appropriation by the mordant of a certain amount of fatty matter from the soap, and the retention and incorporation of it as an essential constituent of the colouring compound which is to remain upon the cloth. To fulfil the latter function, it is evident to the chemist that the soap employed must be of a very neutral nature, and nicely balanced in its proportion of fatty acid and alkali; for if it is demonstrated that in such a colour as madder red, as it exists in a finished print, there is found a definite proportion of fatty acid, and that this fatty acid is an essential constituent of the colour, it is clear that the dyer cannot hope to succeed in forming such a combination from inferior or badly made soaps, and therefore cannot hope to produce the best kind of colour.

Purples and lilacs of the best quality can be obtained from several madder products without the use of soap, although soaped work has a softer and better appearance; but for madder reds and pinks, or with alizarin, the use of soap seems up to the present time a matter of absolute necessity, and it is quite certain that full and strong reds do actually absorb a large proportion of fatty matter from the soap; so much so that highly-soaped reds may be observed to mark off in steaming, and the marking has a decidedly greasy character; and the presence of fatty matter in the colour can be proved to demonstration, while the uncoloured parts of the print have at most absorbed a very trifling amount of it.

The modern system of soaping madder work is in a series of connected becks, six or eight in number; they are similar in the body to dye becks, but the angular wince is replaced by a cylindrical solid or hollow wooden bowl, provided with a smaller pressing roller at top, and a stripping wince below to take the cloth off the large bowl, to which it has a tendency to adhere. The cloth is entered at the first beck, and progresses in a spiral manner through the whole series; the last beck may be in connection with a washing machine. There are many modifications in details of the continuous soaping arrangement, but most of them are of too minute a nature to need entering upon. The chief difficulty in working is when soaping at or near the boiling point; then the pieces are very subject to become entangled, and come up in "lumps," interrupting in a very annoying manner the progress of the work. The best mechanical arrangement to avoid this inconvenience is to have several mid-feathers in the beck, so as to keep the pieces as much as possible under their proper peg-rails; having the draw-rollers fixed at a height of say 3 feet or more above the level of the fluid is also a great assistance, for the greater the distance between the beck-level and the nip, so much more the chance of knots and folds shaking themselves free before they arrive at the nip; there is of course a loss of heat by the pieces passing through the cold air, but that is amply compensated for by ease and regularity in working. The inclination of the holes and depth of the steam pipe also influence the running of the pieces; the pipe should be as high in the liquid as it can be safely placed, and the direction of the steam should be at an angle of 45° upwards and towards the back of the beck, influencing by its currents the piece only as it is leaving the liquor.

Fig. 24.



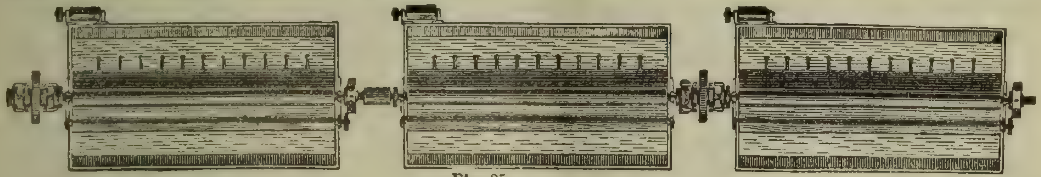


Fig. 25.

By an intelligent observance of these and other precautions, the continuous system can be advantageously applied to most styles of work, for the temperature, time, and strength of soap are as completely under control as in the old interrupted system, and there is a notable saving of labour and damage to cloth The last beck of the series is kept supplied with hot water and soap, so as to maintain it clean, while the first beck, which wants a good deal of attention, must be so kept supplied with extra soap when required that there is always some lather on the top. The pieces fresh from the washing destroy a good deal of soap, and if the first beck is allowed to break it may dirty the pieces and cause some trouble afterwards; the exhausted and dirty soap liquor is allowed to run freely away from the first beck.

Figs. 24 and 25 show the elevation and plan of a range of three soaping becks working upon the continuous spiral system.

Further remarks upon soaping are general, and do not refer to any special method or apparatus: and when second or third soaping is mentioned, the single beck, or old system, which is still the most largely followed, is that which is meant.

The madder pink style requires the greatest amount of soaping and the most care, and will be first considered. The preliminary soaping for pinks is done at a temperature which should not pass 140° Fahr., and which should be continued long enough to cleanse the cloth and colour from all the impurities not removed by the washing machine. If a much higher temperature be employed in the preliminary soaping, it will be found that the reducing or cutting of the pinks afterwards is less perfect and satisfactory; and if the temperature be much lower, or the time or quantity of soap allowed not sufficient, there will be an unnecessary loss of colour and a probable injury to the whites in the subsequent processes.

The next treatment of pinks is peculiar to this style. It consists in passing them through an acid solution until the colour changes from the crimson shade into a scarlet or orange-toned red. This operation, which is called "avivage" in French, has no fixed name in English, but is widely known a "cutting." Various acids and acid bodies have been employed, as sulphuric and nitric acids, but the preference is given to a strongly acid solution of tin called the oxymuriate of tin. This preparation is found in trade, but frequently made on the print works by taking say 16 lbs. of the crystals of tin, melting them in their water of crystallization, and adding by small portions 20 lbs. of ordinary nitric acid. There is a violent effervescence and evolution of red fumes, and the oxymuriate is left as a dense somewhat opaque fluid. The quantity of this solution necessary to be employed varies with the quality of water and the depth of colour dyed. The temperature and time also have to be left entirely to the discretion of the dyer. Sometimes the cutting can be done with cold water (that is when the pinks have been dyed at a low temperature and soaped also very lightly); at other times a high temperature must be used. The dyer is guided by the change of colour which takes place, and arrests the operation when it is sufficiently advanced. For the finest and most delicate pinks the change of colour is pushed on until the hue is decidedly orange, but it is mostly preferred to do this at twice, with a soaping between; for fuller and redder pinks the dyer stops the cutting when the colour has only undergone a slight change towards the orange shade. The pieces are washed out of the acid liquid, and then submitted to solution of soap at or near the boiling point. A great deal of colour is dissolved off by the soap, and the boiling with soap is protracted for an hour or more, or repeated with a fresh bath. The beauty of fine reds and pinks depends greatly upon the soaping, and it is sometimes repeated again and again as long as the shade continues to improve. When the pieces have been freed from all loose colour they are frequently boiled with soap in a close pan to give the best possible improvement to the shade. For this purpose a good quality of soap is absolutely necessary; and when the shade of pink is desired to be very bright and fiery, a certain amount of tin crystals is dissolved in the soap. This "panning" is sometimes done under a pressure of 5 lbs. of steam, and is protracted for five or six hours.

This introduction of an acid tin salt in the madder styles may be traced back to the turkey red dyers, but its adoption for printed pink goods is due to the Alsatian printers. It dates from the early years of this century, and gave them a distinct advantage in these colours, which were for long known under the name of Swiss pinks. The French printers may be said as a rule to prescribe or recommend the addition of a certain amount of tin salt to soaping for all styles of work; and their belief is that some tin soap is formed, which becomes part of the colour. Whether this be the real result of such addition, or whether the action be to form a neutral or acid soap, which more easily parts with its fatty matter, or whether it is merely a corrective for a too alkaline soap, is difficult to say. This much may be said from personal experience, that while a really well made soap is so influenced by addition of tin as to exercise a more active impression upon reds in brightening and yellowing them, its cleansing powers are much diminished; and to obtain a good result, an increased quantity must be employed. In fact, a lengthened and varied practice has not convinced the writer that there is any real advantage in using tin crystals along with soap for any kind of madder work where a good quality of soap is employed.

As before stated, the liberal use of soap seems to be a necessity for all good reds from madder and its derivatives and from artificial alizarin. Good dark reds can be dyed from garancin and garanceux, but they do not stand the cutting process; and to obtain them of a lustre and depth approaching madder red, they require an extraordinary amount of soaping—five or six soapings of an hour each not being too much.

Artificial Alizarin yields a good heavy red by dyeing. It does not seem to be improved by cutting, and requires a good soaping to yield a fair colour. The process of dyeing with artificial alizarin is carried out the same as for madder; the same mordants somewhat reduced are employed, and the subsequent treatments are the same.

The employment of artificial alizarin or extract of madder in dyeing possesses several advantages over ground madder, which arise from the pure and concentrated state of the colouring matter. The dyeing can be accomplished in a shorter time. If the dyer perceives that the goods are likely to be underdyed from an insufficient amount of colouring matter being used, it is possible to remedy the defect by adding a fresh supply of alizarin or the extract. This could not be done with madder without danger of irregularity, and the only safe remedy was to repeat the dyeing. A less amount of water can be used in dyeing; the washing is more easily effected; baths not quite exhausted can be used for a fresh dye by strengthening up; the soap liquors are cleaner, and throughout it is found that there is much less labour and much less fuel required. It appears that the colours are not quite as fast from artificial alizarin as from madder, and it is found desirable or necessary to steam them between dyeing and soaping. This necessitates drying, and some dyers believe that the goods should be padded in the soap and rosin solution used for pinks, while others believe that simply steaming is sufficient. If this additional operation is found indispensable, there will be styles, such as white ground purples, and other light prints not requiring much dyestuff, which it may be found economical to dye with madder, in order to avoid the delay and expense of the intermediate steaming.

As the topical applications of artificial alizarin and extract of madder yield the same styles as madder, and require the same after treatments, it is proper to treat of them here. The recipes for alizarin colours differ considerably in detail. Some selections are here given of English and German origin, and variations and modifications are afterwards noticed:—

The thickening paste is prepared in advance from—
1 gal. of water.
3 " acetic acid, at 8° Tw.
8 lbs. wheaten starch.
Boiled together, and allowed to go cold.

Dark Red Alizarin.

2 gals. of thickening.
1½ " of alizarin, at 10 per cent.
2 pints acetate of alumina as below.
3 oz. olive or Gallipoli oil.

Light Red Alizarin.

6 quarts Senegal gum water.
2 " acetic acid.
2 " alizarin, at 10 per cent.
1 pint acetate of alumina.

Dark Purple Alizarin.

2 gallons of thickening.
3 quarts of alizarin.
3 pints of acetic acid.
1 pint of iron liquor at 24° Tw.

Light Purple Alizarin.

8½ quarts gum water.
3 " acetic acid.
2 " alizarin.
½ pint acetate of iron at 24° Tw.
1½ " acetic acid.

Acetate of Alumina for Alizarin.

1 gallon boiling water.
6 lbs. white acetate of lead.
6 lbs. alum.

The above colours are of English adaptation, and intended for Perkins' alizarin; they present the simplest form of composition for these colours, and are more suitable for working with pigments in five or six coloured patterns than the more difficult style of covered pinks. They are directed to be steamed for two hours, the first hour and half with moist and low steam, and the last half hour with high and dry steam. The following recipes are slight modifications of some furnished by GESSERT BROTHERS of Elberfeld, and are all to be made with an alizarin paste containing 15 per cent. of dry matter:—

Single Red Grounds Alizarin.

4 lbs. alizarin, 15 per cent.
5 lbs. acetic acid, 10 Tw.
1 gallon water.
1 lb. olive or Gallipoli oil.
1 lb. acetate of lime at 17° Tw.
2½ lbs. wheaten starch.

These ingredients are well boiled, cooled, and then is added—

1 lb. acetate of alumina at 24° Tw.

Dark Red Alizarin.

3½ lbs. alizarin, 15 per cent.
1 gallon of thickening.
7 oz. nitrate of alumina, 24° Tw.
10 oz. acetate of alumina, 20° Tw.
8 oz. acetate of lime, 24° Tw.

Red for Pigment Style Alizarin.

2½ lbs. alizarin, 15 per cent.
1 gallon of thickening.
5 oz. nitrate of alumina, 24° Tw.
10 oz. acetate of alumina, 20° Tw.
7 oz. acetate of lime, 24° Tw.

The thickening for reds is as follows:—

Thickening for Red Alizarin.

6 lbs. wheaten starch.
2 gallons water.
4 lbs. acetic acid, 10° Tw.
1 gallon tragacanth gum water.
1½ lbs. olive or Gallipoli oil.

well boiled together.

For dark red, covered with pink, the colour is composed as follows:—

1 gallon of thickening.
2 lbs. of alizarin, 15 per cent.
10 oz. acetate of alumina, 18° Tw.
5 oz. acetate of lime, 24° Tw.

The pink for covering is made by reducing the red with the above thickening, according to the depth of colour required, or the strength and closeness of the engraving.

The acetate of alumina to be used for these colours is not prepared by double decomposition of alum and acetate of lead, but by dissolving precipitated alumina in glacial acetic acid. This is a troublesome process, and, according to the writer's experience, not at all necessary for obtaining good colours. The process is as follows:—The alum is dissolved in a tub of hot water, and crystallized carbonate of soda added as long as any precipitate is produced. The precipitate is washed six or eight times by the decantation method—well understood in colour shops—drained on a calico filter, and then pressed, to obtain it as dry as possible, when it should contain 15 per cent. of dry matter. This pressed paste is then dissolved at a temperature of 80° Fahr. in the strongest acetic acid. On the Continent the glacial acetic acid is used by all the most successful works for topical alizarin colours. This acetate of alumina is a very unstable mordant, and in a short time will deposit nearly the whole of the alumina in its insoluble modification, rendering the mordant useless. It is better to use purified sulphate of alumina, quite free from iron and acetate of lead, in the manner used for making ordinary red mordants.

The nitrate of alumina is made from one gallon of water, 5 lbs. of alum, and 5 lbs. nitrate of lead.

The making and printing of alizarin colours requires the greatest care and cleanliness, because the purity of the shades is injured by the least contamination with metals or other colours. The reds are seen to be very strongly acid, and the thickening cannot be safely boiled in copper pans, unless these have been previously cleaned with the most scrupulous exactness. It is recommended to use enamelled copper or iron pans, or to boil the thickening in an earthenware vessel. In working, a wooden colour-box is to be employed, and, if possible, a composition or silver-nickel doctor, instead of a steel one. If only a steel doctor will clean the roller, it may be covered with engravers' varnish on the side next the colour, up to within a quarter of an inch of the edge, and the mandrill must be lapped near the roller, so that the colour will not come in contact with it. If, during the working of a pink cover, the machine be stopped for twenty seconds, the doctor shows a dark mark all across the piece, and for a yard or more the shade is perceptibly injured by the action of the iron dissolved from the doctor.

The pieces may be steamed immediately after printing. If covered pinks are being worked the dark pink never comes up with satisfactory distinctness unless it is steamed separately, that is, before covering: a half-hour's steam is sufficient. For the dark pink the time of steaming is usually two hours; and though many different ways of steaming have been proposed, it seems proved that no method is better than having an abundance of low and quite damp steam. In endeavouring to get the steam low and moist from a high pressure supply, care must be taken that there is sufficient of it to make certain that the cloth is speedily heated up to 212° Fahr., and kept at that temperature during the whole time: any higher temperature is not only unnecessary, but very likely to yield dull flat colours, which cannot be brightened by soaping.

After steaming, the goods may be hung in the ageing room for twenty-four hours, or they may pass on directly to the dye house. There are different methods of commencing the treatment in the dye house. In some cases the goods are passed in the dunging dolly through warm water and chalk. Silicate of soda is also employed; and for purples, arseniate of soda is sometimes used, and frequently nothing but water is used. The pieces are only from one to two minutes in the dunging dolly, and it may be looked upon as only a convenient method of wetting out preparatory to washing. The washing must be continued until the loose matters are removed; for if the pieces go imperfectly cleaned into the soap, the liquid becomes very dirty, and the whites and colours are injuriously affected.

The soaping is commenced at about 140° Fahr., and there must of coarse be sufficient soap to give a free lather. Here, as in other cases referred to previously, the Continental colourists insist upon the benefits to be derived from the addition of tin crystals to the soaping liquor; and here, as before, the writer never could satisfy himself that there was any advantage in it, while it certainly destroys soap. During the first soaping the dyer can form a tolerably correct idea as to whether the colour will turn out good or not. If the red and pink seem hard, that is, resist the action of the soap, and if the soap liquor only acquires a brownish and not a full red colour, an inferior result may be predicated. Either the colour has not been well made, and the proportion of mordant has been too great for the alizarin, or the printing has not been successful, not full enough, and probably accompanied by sticking in and a separation of the colouring principle from the mordant, or the steaming has been too high, or something else wrong has occurred. If the soap liquor becomes fairly, even deeply coloured, and the colours themselves seem softening and yielding to the action of the soap, a good result may be anticipated. The temperature must not be pushed much beyond 140° Fahr. for half an hour; for in well charged patterns much colour is removed, and the soap liquor becomes very dirty. The soaping is repeated at least twice more for reds and pinks, and at a higher temperature (say up to 180° Fahr.); and if it seems desirable the goods are boiled in clean soap for an hour or longer.

It will thus be seen that the artificial alizarin applied topically requires as much soaping, and probably longer soaping, than the same styles from madder, in order to obtain a colour similar to that from madder. Setting aside those designs in which pink, red, and purple from alizarin are combined with black, blue, green, and orange from aniline or pigments, and in which there is no question of comparison between madder and alizarin, it may be asked what are the advantages derived from the employment of alizarin in the old madder styles. The advantages are—first, in the cost, which may, however, be only a temporary advantage; and secondly, in the facility of application, owing to which establishments that were never able to do the highest class of madder work, either in pinks or purples, can produce a very close imitation of them, and supply the wants of the market. In other respects it may be said that though artificial alizarin gives results very similar to madder, the best alizarin colours are not equal in solidity or beauty to the best madder colours; and apart from the cost of the primary material, the expenses of application are rather in favour of madder, the alizarin colours requiring more steam and more soap than madder colours.

With regard to the composition of alizarin colours the following notes may be recorded:—Nitrate of alumina tends to give a yellower red than the acetate. The nitrate cannot of course be used without acetate of alumina or acetate of lime in conjunction, on account of its destructive action upon the cloth. The use of acetate of lime is believed to improve the regularity and the fastness of the colour. Tragacanth gum water, which is not much used in this country, is of very extended use on the Continent for many colours, and is thought to contribute to their easy working in the printing machine. The large amount of oil employed in the alizarin colours is with the intention of improving the working, and causing at the same time a fixing of it upon the cloth to assist as a mordant. The oil should be of good quality. It is sometimes recommended to use the emulsive oil, as employed in turkey red, but it possesses no superiority over the ordinary oil.

Alizarin gives a pleasant shade of chocolate with chromium mordant by steaming; but it is rarely employed, requiring as much colouring matter as strong red to obtain full shades.

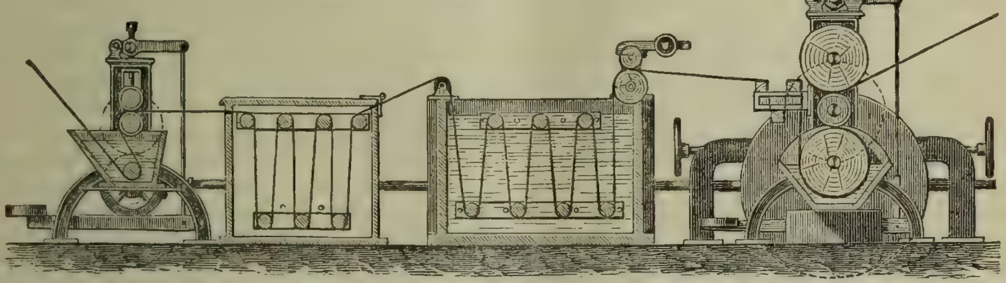
The soaping of madder purples requires no particular notice. They require a good quality of soap; and though not absolutely requiring the presence of fatty matters, they are much improved by them, and the colours apparently raised as if in relief upon the surface of the cloth. This effect can only be obtained by the free use of a well made soap. The temperature for ordinary bold purples should not exceed 180° Fahr. For a softer and more delicate shade of purple the goods may be "panned" or boiled with soap in a close vessel for one or two hours, and in this case the addition of crystals of tin has a decided influence in reducing the tone of the colour.

Garancin and pincoffin, or commercial alizarin dyed goods, are sometimes slightly soaped to improve the colours; garancin reds are improved by steaming after dyeing. Madder pinks are also often steamed after dyeing and before soaping; this hardens the colour, and is useful in cases where the light pink is not well up. For general work it is not to be recommended, because it injures the shade.

Flowers of madder behave in every respect like madder, but do not stain the whites so much, and do not require so much soaping to bring up the colours.

CLEARING OF WHITES.—Formerly the dye house operations concluded by passing the goods in a warm and very dilute solution of bleaching powder, to remove the tinge of colour on the whites. This operation is now seldom performed in the dye house, and the clearing may be said to be universally accomplished by the padding machine and steam box, which should be in connection with a drying machine. After the final washing in the dye house the goods are therefore passed through the squeezers, to remove as much water as can be expressed by mechanical means, or in the non-continuous process they are partially dried by the hydro-extractor; and those goods which do not require much clearing are at once sent on to the drying machine, or in the still wet state they are chlored and dried. But generally the chloring in the wet state is confined to garancin styles which have strong colours, and the whites of which require strong treatment to clear them, and they are chlored again a second time in the dry state.

Fig. 26.



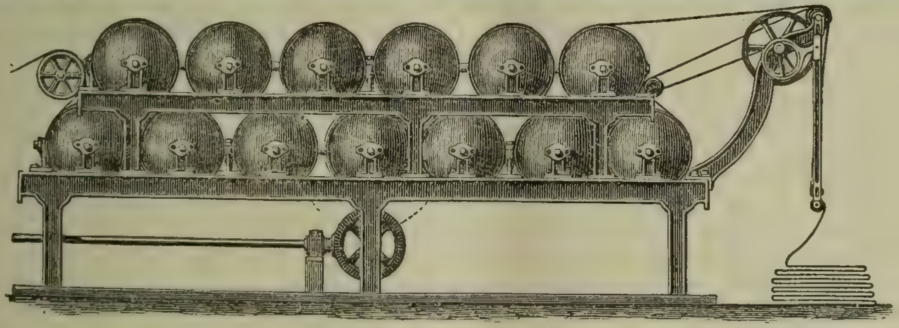


Fig. 27.

The chloring machine consists essentially of a box to contain the solution of chloride of lime, and two rollers working in a frame and placed immediately over this box; the upper roller is covered with thick india-rubber, and the lower may be of brass or copper. The cloth either passes directly between the rollers, receiving the bleaching liquor from the under roller, which, revolving in the fluid, carries up a sufficient portion, or, what is much preferable on the ground of regularity and certainty, the box is provided with a roller or fixed rail near the bottom, and the piece passes under this and consequently right into the bleaching liquor, and then between the metal and india-rubber covered roller, to express the excess out. Attention must be directed to the state of the india-rubber roller, which must be kept in good order, or else there will be an unequal amount of the bleaching liquor on different parts of the cloth, with the probable result of the middle or sides of the piece being either under or over cleared. The cloth passes directly into the steaming box, which is placed as near as possible to the frame and rollers. This box is provided with small copper rollers in the interior, by means of which the piece travels three or four times backwards and forwards; and steam is admitted by perforated pipes so arranged that it blows directly upon the whole width of the piece; and the steam must be in such quantity as to raise the temperature of the piece almost instantly to the boiling point, and be in such excess that it blows out freely and forcibly at the slits which serve for the entering and exit of the cloth.

Fig. 26 shows a chloring arrangement combined with a starching mangle; and Fig. 27 shows the drying machine which is connected, and over which the starched goods pass to be dried.

The strength of the solution of bleaching powder must evidently vary with the nature of the goods under treatment; for heavy garancin styles it may be as strong as 1° Tw., or stronger, while for delicate shades of purple, and for some of the aniline colours, it must not be one-fiftieth of that strength. Some difference will arise from the quantity of liquor which the piece is allowed to carry with it, depending upon the set of the rollers, but as a rule the piece should have a good nip, and it is preferable to have a smaller quantity of a strong liquor than a large quantity of weak liquor.

In the best arrangements of machinery the cloth is passed on without stopping into the water mangle, where it passes through a trough of water to wash out the remains of the bleaching liquor; then between wooden bowls and a brass roller to straighten and squeeze it; and lastly, on to the tins of the drying machine.

Finishing Operations.—With the exception of turkey red, and sometimes heavy blue styles, all prints are, as a rule, submitted to a finishing operation, the object of which is to stiffen, smooth, and press them for the market. This final process does not involve any chemical principles, and might seem so subsidiary to an outsider as not to call for any detailed notice; but it is a matter of the first importance in the trade, and at times a subject of much trouble and anxiety. When the artist, the chemist, and the machinist have together succeeded in producing an elegant print, good in design, perfect in execution, and rich and fast in colour, they might think their work done; but unless the finish be satisfactory, they will find all their labour and skill have been thrown away on unsaleable goods. The fastidiousness and capriciousness of buyers from different markets, the importance they attach to the degree of stiffness, the amount of gloss and the peculiarity of feel of a finished print, the difficulty of conveying their meaning in words, and the apparently contradictory and incompatible qualities they demand, are a frequent perplexity to the print works manager, and he has to call to his aid experience, machinery, and complex processes to satisfy the wants of the market. Nearly every market has its own favourite finish, but we can only give general ideas and hints as to how various kinds of finish are produced, so as to communicate the desired stiffness, gloss, and feel, without injuring the colours.

As above stated, some styles are sent to market unstiffened, but this is exceptional. In the case of turkey reds the lustre and fine softness of the colour is so much injured by starching, that in most markets they are sold either entirely without stiffening, or with very slight stiffening, and the only finishing operation they are subjected to is a slight calendering or mangling, to lay the cloth smooth and free from creases. The employment of the water mangle, and the squeezing of the pieces full width, contribute greatly to giving an even and uniform surface to calico. Navy blues, for similar reasons, are completed with a soft finish, and to heighten the depth of colour are sent as damp as possible to the market. Other prints are rarely made up without some stiffening, but are sometimes required by certain markets. To the genuine connoisseur and critic the colours on a print never look so well as when unstiffened.

The home market in Great Britain takes ordinary good prints with a medium amount of stiffening, and does not require any glaze or lustre on the surface. The old starching apparatus, and one still much in use, consisted of a framework holding three rollers, the full width of the calico to be finished, the centre roller of small diameter of copper or brass, and the two large rollers of hard wood, usually sycamore or maple. The starch boiled up in a pan, and mixed with blue, is contained in a trough; the calico to be finished is drawn through the starch, and the excess pressed out by causing the cloth to pass between the wooden and metallic rollers. Sometimes only one wood and one metal roller are used; and in other cases the cloth is not drawn through the starch, but removes a sufficient quantity of it from the large wooden roller which revolves in it. After receiving the starch, the calico passes over the drying machine, and then is passed between wooden and metal rollers to smoothen or mangle it, as much pressure being put on as the apparatus will bear. The remaining operations are measuring, folding, and making up.

In this somewhat old-fashioned method, the points to be attended to are the thickness of starch, the quality of the starch, and the quantity put on the cloth. The thickness of the starch varies according to the amount of stiffness required, and the quality of the calico; for superior kinds of calico it is used thin, for low qualities it is used thicker, in order to give it more weight and a substantial appearance. The kind of starch to be employed depends in a great measure upon the kind of finish required. Perhaps the general demand in the trade is for a finish which gives the appearance of fulness, without feeling stiff; what is called the "clothy" feel. Sago flower and potato starch are good bases to go upon, and there are several mixtures of starches sold in the trade under the name of "finishing starches," which are of various composition, being mixtures of sago starch, potato starch, maize flour, rice starch, and other similar products, which are found more or less suitable for the purposes of printers. In the boiling of the starch, it will generally be found that the lower the temperature at which the starch can be dissolved, the better it is for finishing; if the starch be over boiled, it acquires a gummy character, and the calico is found to have a thin, hard, and flinty finish, with a tendency to curl up when left in a dry place. To counteract the stiffness and harshness which inferior starch or too much starch communicates to the cloth, it is customary to mix some fatty matter, or glycerine, or soap, with the boiled starch; tallow, stearine, bone fat, or the so-called finishing pastes, which are usually nothing but very watery soaps, can be employed for this purpose. In finishing prints containing delicate shades, care must be taken that the soap or printing pastes are not too alkaline in their nature, for many fine shades are dulled by a trace of free alkali. Glycerine is useful as giving a softer feel to the finish, and preserving it somewhat humid; some finishes where great weight is required in the cloth have been made entirely of colourless soluble gum, with a large proportion of glycerine. In order to improve the whites, and in some cases even to give a distinct blue tinge to the whites, ultramarine blue is mixed with the starch; other kinds of blue, such as Prussian blue or aniline blue, may be used, but preference is given to a very fine, specifically light variety of ultramarine. It may be noted, that though bluing gives a brighter appearance to the finished print, it is a mistake to suppose that an extra quantity of blue in the starch will neutralize or overpower bad whites; it is only a good white which shows up the agreeable azure tinge of the blue used in finishing.

The inconveniences of the old method of stiffening prints was first felt when dark garancin style came into vogue some twenty years ago. The colours, after finishing, looked dull and flat compared with the unstarched print, and this was soon found to be a defect inherent to the system of applying the starch in stiffening. The layer of starch, which covered the face as well as the back of the piece, not only obscured the colours by its partial opacity, but destroyed the bloom by pasting together, so to speak, the velvety surface of the cloth. To obtain the necessary stiffness of the calico without covering the colours, it was evident that the starch should be applied only upon the back of the tissue, and this could be accomplished by various means, the most convenient of which at first was by padding in the printing machine with an engraved roller. This was followed by the introduction of the back-starching machine, patented by Jones, of Rhodes Printworks. The means used in this machine were chiefly an engraved copper roller revolving in a trough of starch, the excess of starch removed by a doctor, and the cloth drawn with a slight pressure over the engraved roller, which revolved rapidly in a direction opposite to the motion of the cloth. By this contrivance an uniform layer of starch was spread over the back of the piece, and as but little direct pressure was acting upon it, only a small portion was forced through to the face to interfere with the colours of the dye. The drying of the cloth, thus smeared with a superficial layer of starch, presented some difficulties; it could not be run upon the drying tins like cloth uniformly impregnated with starch, for when the starched side touched the heated metal the starch formed a thin semi-solid sheet, for which the metal had more attraction than the calico, and it either adhered to the surface of the drying tins, or came off in semi-transparent films and flakes, but a small portion remaining on the cloth. To avoid this a series of about four skeleton drums, called "lagged rollers," were arranged above the drying tins, and the face of the cloth only came into contact with the steam-heated cylinders, and by passing over four or five of these the starch was sufficiently consolidated to permit the piece to be dried by the usual back and front passage on the remaining tins of the drying machine. To insure a proper adhesion of the starch by means of a sufficiently rapid drying, it is recommended that the drying machine be worked at a pressure of say 15 lbs. of steam in the tins.

Figs. 28 and 29 show the elevation and plan of the back-starching arrangement as constructed by Gadd of Manchester.

It is evident that by this process of applying starch it would be possible to mix with it perfectly opaque materials, such as china clay or barytes, and this is frequently done with low qualities of cloth to give them the weight and feel of a better article.

In the bleaching and dyeing operations calico is elongated to a certain extent, and becomes narrower in proportion; in order to restore a portion of the width lost it is now usual to subject it to the action of certain apparatus, which are known as widening or breadthening machines. There are several different arrangements for this purpose, but the tendency is to employ a modification of one long in use by the white finishers, which consists of two rollers with circular grooves revolving one over the other, the raised parts of one roller fitting into the depression grooves of the other. The cloth is passed between the two rollers, and the edges or selvedges being held by a rope running in a groove, the effect of the action of grooved rollers is to press the already tightened piece into the depressions, and so stretch it in the direction of its width. This operation is usually performed after the starching, and before the mangling or calendering. Stark of Thornliebank has recently patented an arrangement in which these grooved rollers are combined with the drying machine, and the widened cloth immediately passes from the grooved rollers on to the drying tins, and the breadthening effect is made more permanent. Dennison's machine, also much used, consists of two large pullies set upon an axis in such a way that instead of being vertical and parallel they are oblique, and incline to one another for one-half the diameter, and diverge from one another for the other half, so that revolving on one shaft the edges of the pullies are, in one position, nearer to each other than in the opposite position. The cloth to be widened is fed on to the pullies at the point where they are nearest, and the selvedges being held by a strong travelling band of gutta-percha the cloth is forcibly stretched, and its width may be safely increased about one-fifteenth.

For some special classes of prints there are special finishing apparatus. It is only necessary to refer to the "stentering" finish used for muslins and fine cambrics, sometimes also for ordinary cloth bearing check patterns or cross stripes. The stentering frame is commonly a long framework upon which travel endless bands bearing fine pin points. The selvedges of the cloth to be finished are held by these pins; a to and fro motion of the endless bands serves to strengthen the position of the weft-threads of the fabric, and provision is made for applying the starch or size for stiffening, and also for drying the tissue, while it is still held distended by the pins and travelling onwards.

It has been stated that the usual finish for the home market in Great Britain is given by as forcible a pressure as can be obtained from wooden bowls acting upon a brass roller, and between which the cloth is passed; but several foreign markets require a higher finish, that is, a gloss or glaze upon the surface of the print. To communicate this finish the wooden bowls are neither close enough in texture nor strong enough in material to resist the enormous pressure required; and bowls are made by compressing paper or cotton upon iron centres by hydraulic rams, until these usually soft or fragile substances acquire a density and hardness almost inconceivable. When these paper or cotton bowls are mounted on a suitable framework, along with

Fig. 28.

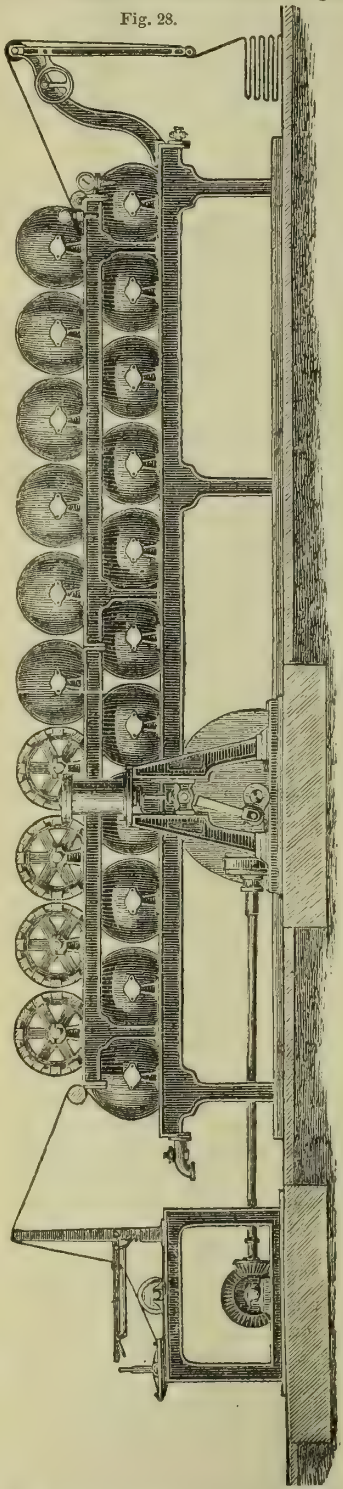
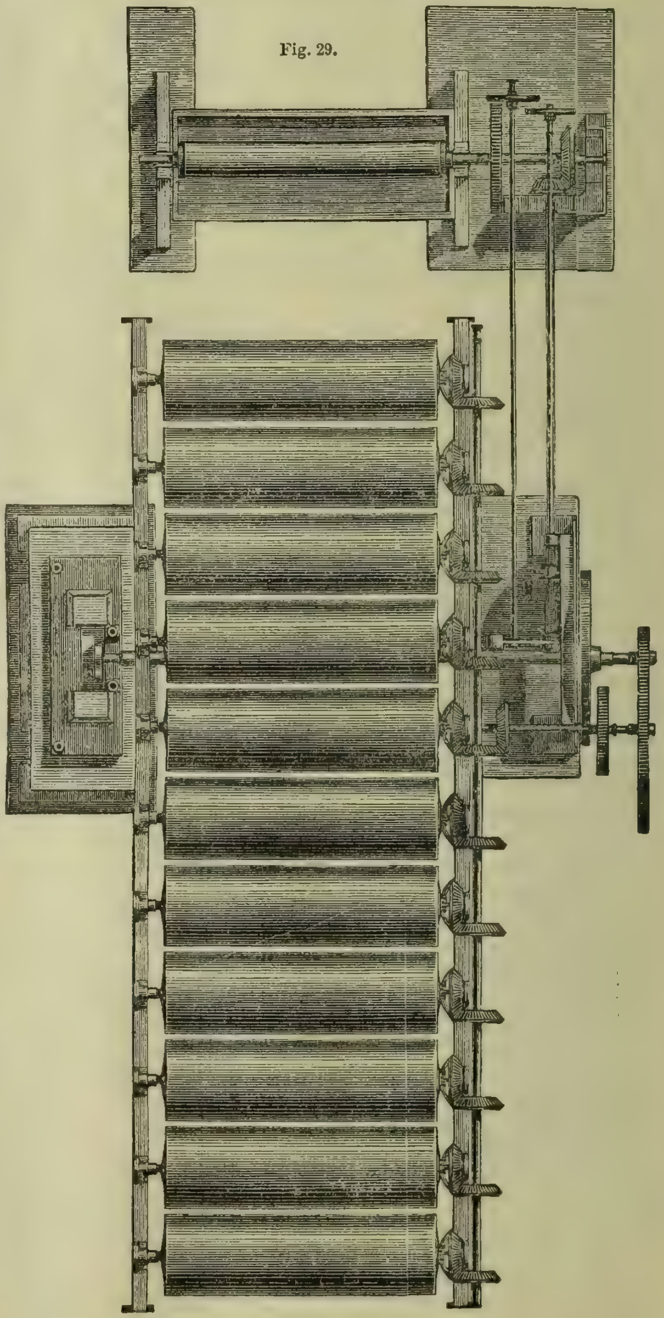
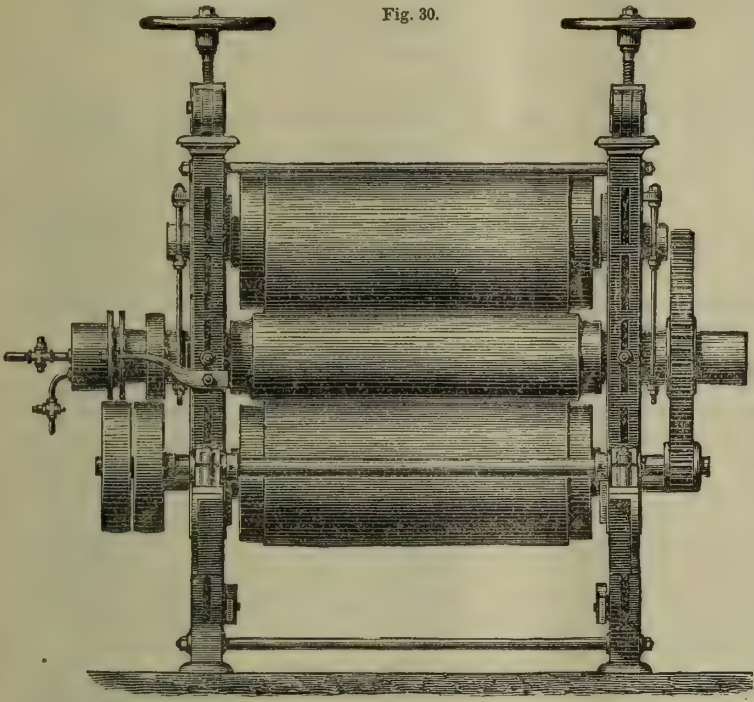


Fig. 29.



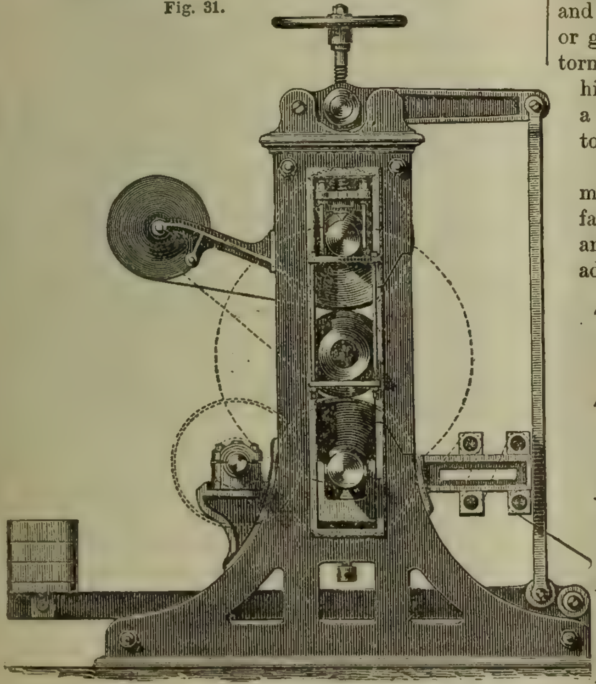
rollers of the hardest iron, the machine is called a calender.

Fig. 30.



The Swissing calender, as seen in Figs. 30 and 31, consists of two paper bowls, with an intermediate iron bowl, and the weight is applied by means of screws and levers; in most cases it is necessary to heat the iron bowl, which is for that purpose made hollow, and heated either by steam or by placing in it heated irons of a suitable shape.

Fig. 31.



When the starched and damped goods are passed through this calender, the surface next to the metal acquires a gloss or polish by the flattening down of the threads, and the heavy pressure brought to bear upon it.

When the highest degree of gloss is required, as for some kinds of furniture prints, it is necessary to have recourse to the friction calender. The friction calender has the metallic bowl usually placed on the top of the two paper bowls, and is driven by a separate wheel. The driving wheels are so speeded that the iron bowl moves faster than the paper bowl, and being pressed with an enormous weight upon it there is a frictional or rubbing effect in addition to the dead pressure. The iron bowl may travel, say 40 inches, while the paper bowl immediately in contact with it travels only 39 inches; the iron bowl is therefore dragged over the cloth which is between them, and thus communicates a high degree of lustre or glaze to the cloth. To prevent the cloth being torn asunder by this dragging, the iron bowl is highly polished, and usually kept lubricated with a minute portion of wax or similar matter, applied to its surface by a properly arranged pad.

Receipts—*Mordants.*—In the preparation of the mordants we distinguish two stages: the manufacture of the red liquor, or acetate of alumina, and its subsequent adaptation for printing by admixture with thickeners.

Standard Red Liquor—

Alum,	40	lbs.
White sugar of lead,	25	"
Boiling water,	10	gals.

Strong Red Liquor—

Alum,	11	kilos.
White sugar of lead,	82·5	"
Boiling water,	32	litres.

Five-fourths Red Liquor—

Alum,	625	grams.
Sugar of lead,	450	"
Boiling water,	2	litres.

Resist Red Liquor—

Acetate of lime at 24° Tw.,	90	gals.
Sulphate of alumina,	272	lbs.
Ground chalk,	34	"

Another Resist Red Liquor—

Water,	1	gal.
Alum,	5	lbs.
Sugar of lead,	2½	"
Soda crystals,	¼	"

The subjoined formulæ have a great reputation for madder-work in France:—

	A.		B.		C.
Alum,	16 kilos.	..	8·0 kilos.	..	10 kilos.
Sugar of lead,	12 "	..	8·5 "	..	10 "
Boiling water,	62 "	..	6·0 "	..	20 "

Red Liquor for Garancin Work (to stand at 15° Tw.)—

Alum,	25 kilos.
Sugar of lead,	19 "
Water,	80 litres.

Strong, ditto—

Alum,	25 kilos.
Sugar of lead,	20 "
Water,	63 litres.

All red liquors should be prepared from the purest materials, the presence of iron in the alum being especially to be avoided. None of them should be made in very great quantity, as they are apt to undergo changes in their composition on long standing. This relates especially to the stronger kinds.

The following are a selection of mordants, or as they are technically called colours, as thickened and made ready for use:—

	Dark Red.		Medium.		Light.
Red liquor at 13° Tw.,	1 litre.	..	1 litre.	..	1 litre.
Water,	1 "	..	4 "	..	15 "
Starch,	240 grms.	..	0 grms.	..	0 grms.
Calcined starch,	60 "	..	2 kilos.	..	6 kilos.
Gallipoli oil,	30 "				
Peach liquor,	164 "				

Another Red—

Garancin red liquor at 15° Tw. (see above),	1 litre.
White starch,	110 grms.
British gum,	75 "

Bright Red—

Strong red liquor (see above),	1 litre.
Acetic acid at 1½° Tw.,	4 litres.
British gum-water, 750 grms. per litre,	9 "
Pipe clay water, 1 kilo. per litre,	5 "

Deep Red (for fine patterns)—

Red liquor at 9° B.,	1·0 litre.
Water,	6·0 "
Brazil wood liquor,	10·0 litres.
Acetic acid at 1½° Tw.,	5·0 "
Alum,	2½ kilos.
Crude sugar of lead,	2½ "
White starch,	3 "
Gallipoli oil,	375 grms.
Nitrate of copper at 109½° Tw.,	375 "

Another Red—

White starch,	2 kilos.
British gum,	4 "
Strong mordant,	10 litres.
Lima wood liquor,	½ litre.
Gallipoli oil,	½ "
Pyroligneous acid,	5 litres.
Muriatic acid,	¼ litre.
Pyrolignite of lime,	1 kilo.
When cold add—	
Tin crystals,	750 grms.

Roses or Pinks—

Boiling water,	30½ litres.	..	38 grms.
Acetic acid at 11½° Tw.,	1½ "	..	2 "
Mordant, 5-4th,	8 "	..	2½ "
Dark calcined starch,	20 kilos.	..	20 kilos.
Gallipoli oil,	375 grms.	..	375 grms.
Oil of turpentine,	375 "	..	375 "

Resist-red, Dark—

Resist-red liquor at 18° Tw.,	12 gals.
Flour,	24 lbs.
Boil well, and when cold add tin crystals,	12 lbs.

This is used to resist chocolate "covers."

Resist-red, Dark—

Resist-red liquor at 18° Tw.,	6 gals.
Flour,	12 lbs.
Boil, and add when cool tin crystals,	3 "

This serves to resist purple "covers."

	Purple 8.		Purple 32.
Boiling water,	48 litres.	..	48 litres.
Black liquor at 10° B.	6 "	..	1½ "
British gum,	36 kilos.	..	30 kilos.
Oil of turpentine,	375 grms.	..	375 grms.

Purple Fixing Liquor—

Arsenious acid,	22½ lbs.
Soda crystals,	25 "
Water,	2 gals.
Boil till dissolved. Add to pyroligneous acid heated to 120°,	50 "
Let stand till all tarry matters are settled, and add muriatic acid,	3 quarts.

Black—

Pyrolignite of iron at 10° B.,	32 litres.
Calcined starch,	10 kilos.
Water,	24 litres.
Bark liquor at 18° B.,	2 "
Logwood liquor at 17° B.,	2 "
Olive oil,	½ "

Browns and Chocolates—

In preparing these the following red liquors are employed:—

Z.	Alum,	10 kilos.
	Sugar of lead,	10 "
	Water,	20 litres.
Y.	Alum,	144 kilos.
	Sugar of lead,	144 "
	Water,	660 "
	Soda crystals,	4 "

With these are compounded—

Mordant Z,	8 litres.
Black liquor at 10° B.,	4 "
Bark liquor at 20° B.,	½ "
White starch,	2·5 kilos.
British gum,	250 grms.
Gallipoli oil,	90 "

Another—

Mordant Y,	12 litres.	..	16 litres.
Black liquor at 10° B.,	2 "	..	4 "
Bark liquor at 20° B.,	¾ "	..	½ "
White starch,	3 kilos.	..	4 kilos.
British gum,	375 grms.	..	375 grms.
Gallipoli oil,	125 "	..	125 "

Brown, for Garancin—

Catechu,	2 lbs.
Water,	53 ozs.
Sal-ammoniac,	6½ "
Boil, strain, and add gum-water,	106 grms.
Nitrate of copper at 80° Tw.,	16½ ozs.
Acetate of copper,	½ pint.

If a redder tone is needed red liquor may be added.

Chocolate—

Black liquor at 24° Tw.,	3 gals.
Red liquor at 18° Tw.,	9 "
Flour,	24 lbs.
Oil,	1 pint.

Chocolate for Garancin—

Red liquor at 18° Tw.,	2 gals.
Black liquor at 8° Tw.,	5 quarts.
Flour,	5 lbs.
Logwood decoction, to sighten,	½ pint.

Drab—

Brown standard,	2 gals.
Muriate of iron (proto) at 9° Tw.,	2 quarts.
Acetate of copper mixture,	6 "
Gum-substitute water (4 lbs. per gal.),	½ gal.

If this is to be used for garancin the quantity of gum-substitute water is increased to 2 gallons.

Brown Standard, referred to above—

Water,	25 gals.
Catechu,	100 lbs.
Boil for about 6 hours, and add acetic acid.	2¼ gals.
Water to make up to 25 gals. Let it stand for two days and run off the clear liquid. Heat it to 130° Fahr., and add sal-ammoniac,	48 "

Let stand, after dissolving for two days, run off the clear, and thicken it with 4 lbs. gum Senegal per gallon.

Acetate of Copper Mixture—

Blue vitriol,	2 lbs.
Sugar of lead,	2 "
Boiling water,	2 quarts.

Dissolve, let settle, and let down with water to 18° Tw.

Stannous Mordants.—The only preparations of tin used by English calico printers are :—

1. Tin crystals (protochloride of tin).
2. Double muriate at 120° Tw. (protochloride of tin in solution).
3. Bichloride of tin in solution at 120° Tw. (known also as perchloride, permuriate, and oxymuriate).
4. Pink salt (double chloride of ammonium and tin, ammonic perchloride of tin).
5. Stannate of soda.

Of these compounds one only, the stannate of soda (otherwise known as "preparing salts"), is in practical use, the stannates of potash and lime and the stannites being rarely, if ever, employed. On the small scale the stannate of soda is obtained by treating a strong solution of perchloride of tin with concentrated soda lye till the precipitate which falls at first is reprecipitated. As thus prepared it contains, of course, chloride of sodium as an impurity. GREENWOOD and MERCER obtain the stannate by putting 22 lbs. of caustic soda, 1 gallon weighing 13½ lbs., into an iron crucible set over a fire, and heated to low redness. When steam is no longer given off, 8 lbs. nitrate of soda and 4 lbs of common salt are added. When the mixture is near the melting point 10 lbs. of feathered tin are added, and stirred in. The mixture grows red-hot and assumes a pasty consistence. When cold it is dissolved in water; allowed to stand, protected from the air till the impurities subside, when the clear liquid is drawn off and evaporated down. In hydrated or crystalline stannate there is present from 20 to 27 per cent. of water. Common salt is sometimes added as an adulterant to a very considerable extent.

Compound preparing salts, such as silico-stannates, arsenio-stannates, phospho-stannates, and alumino-stannates, have been from time recommended on high authority, but they have never come into general use in the trade.

Spirit or Fancy Colours.—The following are a few of the colours in use :—

Black—

Logwood liquor at 8° Tw.,	2 quarts.
Water,	2 "
Copperas,	5 ozs.
Starch,	1½ lbs.

After boiling stir in nitrate of iron at 79° Tw., 5 ozs. (measure).

Blue—

Water,	2 gals.
Yellow prussiate,	2 lbs.
Alum,	12 ozs.
Starch,	2½ lbs.

After boiling and cooling down to 110° Fahr., add—

Nitrate of iron at 82° Tw.,	1½ pint.
Oxychloride of tin at 100° Tw.,	3 pints.

Chocolate—

Sapan liquor at 9° Tw.,	1½ quart.
Bark liquor at 13° Tw.,	1 pint.
Logwood liquor at 10° Tw.,	1 quart.
Starch,	1 lb.

After boiling, cool down to 108° Fahr., and add—

Oxymuriate of tin at 100° Tw.,	½ pint.
Nitrate of copper at 80° Tw.,	¼ "
Olive oil,	½ "

Pink—

Sapan liquor at 15° Tw.,	2 quarts.
Gum-water, 6 lbs. per gal.,	2 "
Sal-ammoniac,	4 ozs.
Bichloride of tin at 120° Tw.,	½ pint.

Pink for Blocking Madder Work—

Brazil wood liquor at 9° Tw.,	2¼ gals.
Sal-ammoniac,	1½ lb.
Pink salt,	4½ lbs.
Sulphate of copper,	1 lb.
Oxalic acid,	2⅝ ozs.
Water (measure),	18 "
Gum Senegal water (6 lbs.),	2¼ gals.
Bichloride of tin, 120° Tw.,	1 pint.

Purple—

Logwood liquor at 9° Tw.,	2 quarts.
Water,	2 "
Copperas,	5 ozs.
Starch,	1 lb.

After boiling, add—

Muriate of iron at 80° Tw.,	½ pint.
Oxymuriate of tin at 120° Tw.,	½ "

Red—

Sapan liquor,	1½ gal.
Verdigris,	½ lb.
Sal-ammoniac,	½ "
Starch,	2¼ lbs.

Boil, let cool, and add—

Oxalic acid,	8 ozs.
Pink salt,	2½ lbs.

Yellow—

Berry liquor at 10° Tw.,	½ gal.
Alum,	4 ozs.
Starch,	8 "

After boiling, add—

Double muriate of tin,	½ pint.

Colours to be Fixed by Steaming:—

Black (*Cylinder*)—

Logwood liquor at 12° Tw.,	1 gal.
Gall liquor at 9° Tw.,	1 quart.

Mordant (as given below),	1 quart.
Flour,	2 lbs.
Starch,	6 ozs.

Boil for about ten minutes, and then stir in half a pint of nitrate of iron.

Mordant referred to—

Acetic acid,	1 gal.
Acetate of copper at 3° Tw.,	1½ “
Black liquor at 24° Tw.,	1½ “
Red liquor at 20° Tw.,	1 “

Blue, Dark (*Cylinder*)—

Water,	3½ gals.
Starch,	7 lbs.
Sal-ammoniac,	1 lb. 6 ozs.

Boil, and add whilst still hot—

Yellow prussiate, ground,	6 lbs.
Red prussiate, ground,	3 “
Tartaric acid,	3 “

When quite cool, add—

Oil of vitriol,	8 ozs.
Oxalic acid,	8 “

(Previously dissolved in 2 lbs. boiling water.)

Tin pulp (as below),	3 gals.

To prepare the tin pulp make a concentrated solution of protochloride of tin (which may be done by dissolving tin crystals in the smallest possible quantity of water, and adding muriatic acid in just sufficient quantity to clear the solution), and add as much yellow prussiate in solution as will throw down all the tin as a prussiate. Wash by decantation, and drain on the filter to a stiff paste.

A *light blue* may be produced by adding to 1 gallon of the dark blue just given 3 gallons of gum substitute water at 4 lbs. to the gallon.

Brown, Light—

Brown standard (see below),	2 quarts.
Gum-water (4 lbs. per gall.),	2 “
Red liquor at 18° Tw.,	½ pint.
Nitrate of copper,	1 “

After printing let lie four nights, and run through a weak solution of arseniate of soda, heated to 180° Fahr. Wash in hot water, pass through very weak chloride of lime, and dry.

Brown, Dark.—The same colour as the above. After printing, steam for half an hour, age for two nights, wash off in a weak solution of bichrome, wash well, and dry.

Brown Standard (as above mentioned)—

Cubic catechu,	25 lbs.
Water,	32 quarts.

Boil for eight hours, and add—

Acetic acid,	2½ quarts.

Then dissolve sal-ammoniac, 10 lbs., in water, 15 lbs. Mix both these liquids well, let them settle, draw off the clear liquid, and thicken with gum-water.

Another Brown—

Berry liquor at 3° Tw.,	2 gals.
Peachwood liquor at 8° Tw.,	1 “
Logwood liquor at 8° Tw.,	½ pint.
Nitrate of copper, dry,	3 lbs.
Alum,	3 “

Buff—

Madder liquor,	1½ gals.
Bark liquor at 10° Tw.,	2 quarts.
Red liquor at 14° Tw.,	1 gal.
Starch,	3½ lbs.

Boil well, and add—

Crystals of tin,	1 oz.

Chocolate—

Logwood liquor at 12° Tw.,	3 quarts.
Sapan liquor at 12° Tw.,	½ gal.
Nitrate of alumina (see below),	1 quart.
Bark liquor at 12° Tw.,	1 pint.
Water,	1 gal.
Starch,	4¼ lbs.

Boil, and add—

Chlorate of potash,	2 ozs.
Red prussiate,	10 “

Nitrate of Alumina (referred to above)—

Boiling water,	2 gals.
Nitrate of lead, crystallized,	6 lbs.
Alum,	6 “
Soda crystals,	1¼ lb.

Dissolve, let the mixture settle, and draw off the clear liquid for use.

Cinnamon—

Cochineal liquor at 8° Tw.,	2 quarts.
Logwood liquor at 8° Tw.,	2 “
Berry liquor at 10° Tw.,	2 “
Alum,	3¼ lbs.
Cream of tartar,	½ lb.
Starch,	1 “

Boil, and while yet warm, add—

Tin crystals,	6 ozs.

Drab—

Lavender liquor (see below),	1 gal.
Blue standard,	1 “
Bark liquor at 8° Tw.,	1 quart.
Gum-water,	from 10 to 17 gals.

Lavender Liquor (above mentioned)—

Red liquor at 18° Tw.,	4 gals.
Ground logwood,	12 lbs.

Steep for 48 hours, and strain off the clear. To obtain a stronger quality increase the amount of logwood.

Blue Standard (above mentioned)—

Water,	2 gals.
Alum,	1½ lb.
Oxalic acid,	9 ozs.
Yellow prussiate,	4½ lbs.
Gum-substitute water,	2 gals.

Green (cylinder work)—

Berry liquor at 12° Tw.,	7 gals.
Yellow prussiate,	15 lbs.
Alum,	8 “
Gum-substitute,	28 “

After boiling, add—

Tin crystals,	2 lbs.
Oxalic acid,	2 “

Dissolve and stir well together.

Green (block)—

Yellow prussiate,	14 lbs.
Boiling water,	3 gals.

Meanwhile mix in another vessel—

Water,	1 gal.
Double muriate of tin, 120° Tw.,	2 quarts.
Gum Senegal water (6 lbs. per. gal.),	5 gals.

Mix the two liquids thoroughly by pouring them backwards and forwards, and stirring the whole very carefully. When thoroughly mixed and clear, add—

Berry liquor at 10° Tw.,	6 gals.
Tartaric acid,	5 lbs.
Oxalic acid (dissolved in 2½ gals. water),	1¼ "
Acetic acid,	3 pints.
Extract of indigo,	12½ ozs. mea.

Green for Blotch Grounds—

Bark liquor at 10° Tw.,	4 gals.
Starch,	6 lbs.

Boil well together, and add—

Alum,	2½ lbs.
Yellow prussiate,	6 "
Tartaric acid,	3 "
Oxalic acid,	¾ "
Tin pulp,	1 quart.

Steam greens are frequently "raised," *i.e.*, brightened after printing, by passing through a weak solution of bichrome.

Dark Grey—

Gum-water,	2 gals.
Lilac standard (see below),	1 "
Yellow prussiate,	2 lbs.
Hot water,	½ gal.

Lilac Standard—

Logwood liquor at 12° Tw.,	4 gals.
Red liquor at 18° Tw.,	4 "
Oxalic acid,	2 lbs.
Sal-ammoniac,	2½ "
Verdigris, crystallized,	20 ozs.

Lavender—

Lavender liquor (see above),	2 gals.
Blue standard (see above),	2 "
Gum-water, to shade,	12 to 24 gals.

Lilac—

Pink standard (see below),	3 gals.
Purple standard (see below),	1 "
Gum-water,	3 "

Pink Standard—

Cochineal liquor at 6° Tw.,	2 gals.
Alum,	1 lb.
Cream of tartar,	1 "
Oxalic acid,	4 ozs.

This standard, thickened with 2 gallons of strong gum Senegal water, serves for a pink steam colour.

Purple Standard—

Logwood liquor at 12° Tw.,	1 gal.
Alum,	6 ozs.
Red prussiate,	4 "
Oxalic acid,	2 "

If thickened with 4 gallons of gum-substitute water this mixture is a good steam purple for cylinder work. If for block work 6 gallons of gum-water are needed.

Pink (*Sapan*)—

Sapan liquor at 3° Tw.,	1 gal.
Pink salt,	1 lb.
Sal-ammoniac,	8 ozs.
Oxalic acid,	1 oz.
Blue vitriol,	1 "
Thick gum-water,	1 gal.

Pink, Cochineal—

Cochineal liquor at 8° Tw.,	2 gals.
Starch,	2½ lbs.

Boil a short time and add—

Oxalic acid,	6 ozs.

Dissolve and strain. After printing steam for forty minutes at a pressure of 3 lbs., let lie over night, run through very weak alum water, and finish.

Purple, Deep—

Logwood liquor at 16° Tw.,	2 gals.
Soda crystals,	½ lb.
Red liquor at 20° Tw.,	2 gals.
Red prussiate,	1 lb.
Oxalic acid,	1 "
Gum Senegal,	12½ lbs.
Sapan liquor at 8° Tw.,	1 gal.
Bark liquor at 12° Tw.,	5 ozs., mea.
Nitrate of alumina,	25 "
Alum,	10 " weight.
Chlorate of potash,	1¼ "
Starch,	1 lb. 14 ozs.

Stone-colour—

Lavender liquor,	2 gals.
Blue standard,	3 "
Black liquor at 12° Tw.,	2 quarts.
Gum-water, to shade,	20 to 35 gals.

Full Yellow—

Berry liquor at 4° Tw.,	2 gals.
Flour,	2½ lbs.

Boil, and add—

Alum,	18 ozs.

When cool, stir in

Tin crystals,	6 ozs.

When all is dissolved, strain. After printing, steam for thirty minutes at 3 lbs. pressure, let lie one night, run through a weak solution of alum, and finish.

The coal-tar colours, certain extracts of madder, and the pigments are generally also fixed by the steaming process. The following are examples of their use:—

Aloes Green—

Chrysammide,	2 grms.
Gum-water to shade.	

This mixture, after steaming, gives a pleasing moss green shade, not affected by boiling water or by madder or garancin becks. Thus a green design may be printed on, or a green ground may be padded in. Iron and alumina mordants may then in either case be blocked in, and the piece dyed up in the madder or garancin beck. Novel and pleasing effects may thus be obtained.

Aloes Rose—

Gum-water,	1 litre.
Chrysammic acid,	2 grms.

This mixture gives a rose on cottons, woollens, or silks without steaming on pieces previously prepared with stannate of soda. By steaming, the rose may be converted into a violet.

Aurine Orange—

Aurine solution,	8 ozs.
Lactarine thickening,	1 gal.

Mix well. To prepare the thickening take—

Water at 80° Fahr.,	7 pints.
Ammonia,	1 pint.
Lactarine,	2 lbs.

Stir till perfectly dissolved. After printing, steam for twenty minutes.

Coralline Red—

Coralline,	100 grms.
Alcohol,	900 "

Dissolve and add—

Solution of caseine,	2250 grms.

To prepare this solution take :—

Caseine,	100 grms.
Water,	300 "
Ammonia,	20 "

Stir till dissolved.

Coralline Yellow—Dissolve yellow coralline in dilute ammonia till the solution stands at 32° Tw. To 1 measure of this liquid take 4 measures of starch-paste, at 14 lbs. per gallon. After printing, dry and steam for one hour.

Eosine Pinks and Roses—Eosine may be applied in the same manner as aurine and coralline.

Saffranin Pink—Mix half a pint of saffranin paste with 10 pints of the following thickening:—

"Acetate of alumina standard,"	1 gal.
Water,	1 "
Starch,	2 lbs.

After boiling cool, and add 1 pint of "arsenic and glycerine standard."

Acetate of Alumina Standard (above mentioned)—Boiling water, 2 quarts; alum, 20 ozs.; dissolve and add white sugar of lead, 1½ lb. Dissolve, settle, and take the clear for use.

Arsenic and Glycerine Standard—Boil 1 lb. arsenious acid in 1 quart glycerine till dissolved, and filter.

After the saffranine is printed, the pieces are steamed for thirty minutes.

Aldehyde Green—

Gum-water,	1 litre.
Paste green,	¼ kilo.
Bisulphite of soda,	150 grms.

Dissolve in the water-bath, and let stand for three or four days before use. It may be steamed after printing, but it succeeds better upon animal fibres than upon calico.

Garnet Brown—

Solution of magenta, 50 grms per litre of alcohol,	25 centilitres.
Gum-water,	75 "
Oxalic acid,	50 grms.
Chlorate of potash,	25 "

Aniline Grey—

Aniline grey (Gris Castelhaz),	1 quart.
Reduction paste,	1 gal.

To prepare the reduction paste take :—

Acetate of alumina,	1 gal.
Water,	1 "
Starch,	3 lbs.

Boil till dissolved, cool, and add—

Arsenic and glycerine standard,	1 pint.

Mix well together. After printing, steam for thirty minutes.

The aniline colours in general, such as magenta, Hofmann's violet, &c., may be fixed upon calico in various methods. Schultz mixes one quarter litre acetate of alumina at 10° B. with 20 grms. arsenite of soda per every 4 grms. of magenta, &c., employed, and thickens with starch which has been previously boiled to a paste separately, using the more thickening the lighter the intended shade. The colour is then added, and the pieces, after printing, are steamed.

Another process is to dissolve gelatine in the proportion of 50 grms. per litre of water. Solution of bichromate of potash is then very gradually added till the liquid is of a straw colour. The aniline dye is then added, and the mixture thickened with dextrine. After printing the goods are exposed for some hours to light, which renders the gelatine insoluble when in contact with chrome. Instead of gelatine lactarine may be used, dissolved in a little ammonia. It must be remembered that the action of light is apt to injure many aniline colours.

The most general method is to mix the colour with albumin or lactarine. The former is the more expensive of the two, but gives better results. For the lightest shades egg albumin is preferred, but for heavy shades blood albumin may be substituted. Both kinds are dissolved in *cold* water in proportions varying from about 8 lbs. down to 2 lbs. per gallon. It is scarcely needful to remark, that colours containing albumin must not be exposed to heat. After printing they are fixed by steaming.

The following examples may serve to illustrate this method :—

Dark Magenta—

Fine flour,	1 lb.
Palest British gum,	8 ozs.
Water,	2½ lbs.
Magenta liquor,	1 pint to 1$\frac{1}{10}$.

Boil thoroughly, and when cold stir in 40 ozs. measure of egg-albumen solution at 8 lbs. to the gallon of water.

The magenta liquor is obtained by taking—

Magenta crystals,	10 ozs.
Methylated spirit (free from shellac),	7 quarts.
White glycerine,	1 quart.
Water,	1 gal.

Dark Violet—

Water,	½ gal.
Fine flour,	4 lbs.
Palest British gum,	2 lbs.
Strong solution of methyl-violet in spirit,	5 quarts.

Boil well, and after cooling add—

Egg-albumen liquor, at 8 lbs.,	½ gal.

The following are instructions for the use of artificial alizarin :—

Red—

Alizarin paste (20 per cent.),	2½ lbs.
Thickening,	16 "
Red liquor at 15° Tw.,	1 lb.
Acetate of lime at 25° Tw.,	½ "

The thickening is prepared as follows :—

Wheat starch,	12 lbs.
Water,	10 gals.
Acetic acid at 9° Tw,	1 gal.
Gum tragacanth,	1¼ lb.
Olive oil,	2 "

Boil the whole well together, and stir till the mixture is quite cold.

Pinks.—The same colour as directed for reds, but diluted with 2 to 3 parts of thickening according to shade.

For styles where two reds are used, the deeper shade being printed on first, the goods are steamed one hour before the second printing. Afterwards they are again steamed for one hour, and aged for twenty-four hours, and passed through one of the subjoined baths at a temperature of 120° to 140° Fahr., not being left in the bath longer than from one to one and a half minute.

Water,	250 gals.
Chalk,	60 lbs.
Tin crystals,	3 "

Or,

Water,	250 gals.
Chalk,	40 lbs.
Arseniate of soda,	10 "

The pieces are then washed, and brightened or cleared as follows:—For 10 pieces of 50 yards each take—

1st. soaping at 120° Fahr., 3 lbs. soap, ¼ lb. tin crystals.
2nd. soaping at 160° Fahr., 3 lbs. soap.
3rd. soaping at 175° Fahr., 3 lbs. soap.

The pieces are washed between each soaping.

Red for Mosaics—

Alizarin paste at 10 per cent.,	8 lbs.
Thickening,	2½ gals.
Nitrate of alumina at 23° Tw.,	9½ ozs.
Red liquor at 15° Tw.,	19 "
Acetate of lime at 25° Tw.,	13 "

Or,

Alizarin paste (10 per cent.),	10 lbs.
Thickening,	2½ gals.
Nitrate of alumina at 23° Tw.,	13 ozs.
Red liquor at 15° Tw.,	19 "
Acetate of lime at 25° Tw.,	16 "

Red, without Oil—

Alizarin paste (10 per cent.),	8½ lbs.
Acetic acid at 12° Tw.,	9½ "
Wheat flour,	3½ "
Water,	2½ quarts.

Boil well, and stir till quite cold, and then add—

Acetate of lime at 29° Tw.,	1 lb.
Nitrate of alumina at 23° Tw.,	2 "
Hyposulphite of lime at 13° Tw.,	3 "

Purple—

Alizarin paste (10 per cent.),	3 lbs.
Purple thickening,	2½ gals.
Pyrolignite of iron at 18° Tw.,	6 ozs.
Red liquor at 25° Tw.,	12 "

Thickening for Purples—

Starch,	19 lbs.
Water,	10 gals.
Acetic acid,	3 quarts.
Gum tragacanth,	1⅛ lb.
Olive oil,	2 "

Boil well together, and stir till quite cold.

Brown—

Alizarin paste at 15 per cent.,	13¼ lbs.
Thickening,	2¼ gals.
Nitrate of alumina at 29° Tw.,	2 lbs.
Red liquor at 19° Tw.,	15 ozs.
Red prussiate of potash, dissolved in water,	15 "
Acetate of lime at 29° Tw.,	17 "

If a yellower shade is required, add to every quart of the mixed colour 1 oz. of bark liquor at 20° Tw. Red colours which are spoiled or too old may be conveniently used as browns by adding per quart of mixed colour ¾ oz. to 1 oz. of red prussiate, dissolved in water.

The mordants used in the above artificial alizarin colours are prepared as follows:—

Red Liquor.—Stir into 6 quarts of acetic acid 30 lbs. hydrate of alumina, warm, filter, and let down with water to the specific gravity required.

The hydrate of alumina is obtained by dissolving separately 72 lbs. of alum and 62 lbs. soda, each in 100 gallons of water. Mix the two solutions, wash the precipitate eight times by decantation, collect it on a filter, and press it. It must be dissolved before it gets dry.

Nitrate of Alumina—

Nitrate of lead	2 lbs.
Alum,	2 lbs.
Water,	½ gal.

Dissolve the ingredients, mix, filter off the clear liquid from the precipitate, and dilute to the strength required. Nitrate of alumina gives a yellower red than does red liquor, and when it is used more acetate of lime is required.

Acetate of Lime.—A solution of acetate of lime at 25° Tw. contains one-fourth its weight of the dry substance. One-tenth of the weight of the alizarin paste is generally required. With fresh qualities of artificial alizarin it is best to determine the amount needed by an experiment on a small scale.

Dark Red from Artificial Alizarin—

Alizarin paste at 10 per cent.,	12 lbs.
Wheat starch,	7 "
Acetic acid at 80° Tw.,	2½ "
Gum tragacanth mucilage (1 lb. per gallon),	1 lb.
Acetate of lime at 80° Tw.,	1¼ gal.
Water,	2 "
Olive oil,	½ "
Boil well, let cool, and add red liquor at 11° Tw.,	10 quarts.

The red liquor here specified is made by dissolving 4 lbs. alum and 4 lbs. sugar of lead in 4 quarts of water, and taking the clear liquid.

Another Dark Red—

Alizarin paste at 10 per cent.,	1 quart.
Acetic acid at 12° Tw.,	15 oz. (meas.)
Starch paste at 2 lbs. per gallon,	3½ pints.
Acetate of lime at 20° Tw.,	½ "
Red liquor (as in last receipt),	12½ oz. (meas.)
Olive oil,	½ pint.

Light Red—

Alizarin paste (from Meister, Lucius, and Bruning), at 10 per cent.	2¾ quarts.
Acetic acid at 12° Tw.,	1½ "
Starch paste at 2 lbs. per gallon,	8¼ "
Acetate of lime at 20° Tw.,	1 "
Red liquor as above,	1¼ "
Olive oil,	3 pints.

Purple—

Artificial alizarin as in last receipt,	2 lbs.
Acetic acid at 8° Tw.,	1 pint.
Gum-gedda water at 4 lbs per gal.	7 "
Black liquor at 10° Tw.,	½ "
Acetate of lime at 20° Tw.,	⅛ "

The following method may be used for the production of a shade resembling turkey red from artificial alizarin. The paste colour, containing 25 per cent. of dry material, is dissolved in five times its weight of spirit, and the solution is at once mixed with a strong solution of muriate of alumina, the pure chloride of aluminium in which should be equal in weight to one-third of the colouring matter. The mixture is then thickened as needful with mucilage of gum tragacanth. To every half litre of the solution is then added 30 cubic centimètres of a solution of best olive oil in sulphuric acid, and alcohol in the proportions of 15 : 1 : 15, and very well stirred in.

The colour must be as thin as possible, so as not to run. The pieces before being printed with this colour are first prepared with red liquor at about 8° B., dried and exposed to the air for two days, passed through a soap-beck made up with 30 grms. of Marseilles soap per litre of water, washed well, and dried. After printing the goods are steamed at a moderately high pressure in ammoniacal steam, passed through a weak soap-beck, washed in a current of water, and brightened by passage through the following solutions:—1. Cold nitric acid sours, 3 cubic centimètres of acid to 1 litre of water. 2. Wash in current of water. 3. Cold nitric acid sours, 5 cubic centimètres per litre. 4. Half a grm. tin crystals per litre, water at 30° C. 5. Wash in current of water. 6. 15 cubic centimètres of chloride of soda at 8° B. per litre of cold water. 7. Thorough washing. The shade is now thoroughly developed, and resists light, air, and soap-lyes like a turkey red.

The muriate of alumina used in this process is made by mixing sulphate of alumina with chloride of barium, an excess of the latter being carefully avoided. The mixture is allowed to settle, and the clear liquid is run off from the sediment.

Natural alizarin, and other improved preparations of madder now in the market, are fixed upon the fibre in the same manner as artificial alizarin.

Pigment Colours, which now play a very important part in printing, and are made to produce some very beautiful effects, are generally mixed with albumin, lactarine, or gluten, and steamed after printing. The following are examples of a few of the principal of these colours:—

Ultramarine Blue—

Water,..............................	7 pints.
Lactarine,..........................	3 lbs.

Stir up well, and add—

Ammonia. at sp. gr. 0·88,............	5 ozs. meas.
Soda lye (caustic) at 32° Tw..........	10 ozs.

Meantime work up

Ultramarine,........................	6 lbs.
Water,..............................	2½ pints.

And mix with the other ingredients.

Ultramarine Blue with Albumin—

Ultramarine,........................	2 lbs.
Water,..............................	1 pint.
Gum tragacanth water at 10 ozs. per gal............................	1 pint.
Egg-albumin liquid at 8 lbs. per gal...	1 quart.

Green (Guignet's)—Grind up 13 lbs. of Guignet's paste green with 1 gallon of blood albumin solution at 3 lbs. per gallon, add to it when thoroughly smooth 1 gallon more of the same solution.

In like manner scarlets are produced with vermillion and ultramarine, grey with lamp-black. orange with chromates of lead, browns with burnt sienna, ultramarine, and ochre, the finest roses with ordinary cochineal carmine, &c. It must be remembered that no acids or acid vapours should be allowed to come in contact with ultramarine work.

Aniline Black.—We may here append a notice of aniline black, one of the most valuable and interesting improvements ever introduced into the art of calico printing. This black, originally invented by the late Mr. J. Lightfoot of Accrington, is unattacked by soap or by the action of light. Strong acids turn it to a dark green, but alkalies restore the black in its original fulness. Chloride of lime turns it a deep brown; but here again the colour may be brought back by washing with water. It can be printed along with madder colours, steam colours, &c., thus producing a variety of novel effects.

The following process was patented by the inventor in 1871:—

Chocolate paste,....................	1 gal.
Basic muriate of aniline,............	48 ozs. meas.
Sulphide of copper,..................	1 pint.

To make the basic muriate of aniline, take—

Aniline oil,.........................	4 quarts.
Best muriatic acid at 34° Tw.,........	3 quarts.

And mix well together.

To prepare the sulphide of copper, take—

Flowers of sulphur,..................	2 lbs. 2 ozs.
Caustic soda at 70° Tw.,............	11½ lbs.

Stir well till dissolved, but without applying heat, and add it to sulphate of copper, 10 lbs., previously dissolved in 20 gals. boiling water. Wash by decantation till the washings are neutral to test-paper, and strain till the bulk of the pulp is reduced to 1 gal. For the chlorate paste, take—

Water,..............................	10 gals.
Wheat starch,.......................	23 lbs.
Sal ammoniac,.......................	5½ lbs.
Chlorate of potash,..................	4 lbs.
Solution of chlorate of soda, as below,	2 gals.

Boil and cool.

The solution of chlorate of soda is prepared from—

Caustic soda, at 70° Tw.,............	1 gal.
Tartaric acid,.......................	7¼ lbs.
Previously dissolved in water,........	3¼ gals.
Heat to 170° F., and add chlorate of potash,...........................	12 lbs.
Dissolve and add a solution of tartaric acid,............................	7¼ lbs.
In water,...........................	6½ quarts.

Stir till cold, strain, press the sediment with a board on which weights are laid. Stir it up again with 6 quarts of cold water, strain and press again, and mix the filtered liquors, which are then set at 28° Tw.

Kœchlin boils together:—

Water,..............................	10 litres.
Starch,.............................	2 kilos.
Calcined starch,.....................	2 "
Aniline,............................	2 "
Sal-ammoniac,........................	4 "
Chlorate of potash,.................	1 "

When about to be used, add cold—

Sulphide of copper paste,............	1 "
Tartaric acid,.......................	2 "

As a general rule, it must be observed that the sulphide of copper, or any other compound used in its stead, should only be added immediately before printing. Salts of cerium have been proposed as a substitute for copper, and found to give even superior results, but their high price will probably prevent their practical application.

The following French receipt has been extensively useful:—

Dissolve 300 grms. starch in 2 litres of water, 150 grms. gum tragacanth in another 2 litres, and 750 grms. of light torrefied starch in a third 2 litres. Equal weights of these three solutions are then mixed together, adding, with the aid of heat, chlorate of potash to the extent of $\frac{1}{30}$ or $\frac{1}{40}$ the weight of this solution, and twice as much muriate of aniline as chlorate of potash. When the colour is going to be used add sulphide of copper equal in weight to the chlorate of potash.

Aniline blacks are not dried hard after printing, except when basic salts of ammonia are used, but merely enough to prevent the colour from smearing. They are then hung up for twenty-four hours at a temperature of 70° Fahr., with about 8° difference between the wet and dry bulb thermometers.

If the aniline black is the only colour printed on the goods the colour is raised by passing through boiling soap-lye, or through a carbonate of soda beck, 2 ozs. per gallon, at 160° Fahr., or through milk of lime. If a browner tone is required they are passed through a weak and hot bichromate of potash beck.

If the aniline black is accompanied with steam-colours the pieces are passed through ammonia *after* the ageing process, but *before* steaming. When aniline black is accompanied by the mordants for madder work it is sufficiently raised by the dunging process.

For preparing aniline blacks, Hartmann advises the use of samples of aniline which boil at from 180° to 185° C. Such as boil above 192° C. are found to give dirty browns.

A recent suggestion is the use of the ferrocyanide and ferricyanide (prussiates) of aniline instead of the muriate.

Printing Woollen Stuffs.—The great attraction which the fibre of wool has for colouring matters enables the printer to dispense with the preliminary mordanting which is in general given to calicoes, even to preparing them for steam-colours. The greatest care, however, is required in the bleaching or sulphuring of the wool, and more especially in the *azuring* which constitutes a part of that process. If salts of copper or tin are present, these will infallibly combine, under the action of the steam, with the sulphur adhering to the wool, unless it has been bleached in the most perfect manner, and spots or discolorations will be found after the steaming, which will be ruinous to the whole process. (See Bleaching.)

Chevreul has clearly established that these spots or stains are generally due to the presence of a compound of copper, or, more rarely, to that of a compound of tin with the sulphur of the wool, and that these stains are developed during the steaming, by the mutual action of the wool and a salt of copper in presence of steam.

The quality of the sulphate or acetate of alumina, which is the base of many steam-colours, must also be taken into consideration. Sometimes ordinary alum is used, sometimes acetate of alumina; and though it is of little importance in the printing of calicoes whether the acetate of alumina has been prepared directly, or by the double decomposition of alum and acetate of lead, it is different in the printing of woollen goods; for that which is derived from the acetate of lead *always retains a certain quantity of the sulphate of lead*, which, according to the nature of the colour, may act on the wool, and give it a brown tint, by reason of the sulphur which it contains.

The principal difference between the printing of woollen and cotton goods consists in the composition of the colouring mixtures applied. The woollen fibre resists the action of acids better than cotton, and hence in the mixtures for steam-colours for woollen goods a greater proportion of free acid is introduced, which has the effect of dissolving the lake, or the oxide of the mordant, and thus of producing a more intimate and a more uniform fixation, imparting at the same time a higher lustre to the shades. It is for this reason that in mixing steam-colours for woollens, a considerable quantity of tartaric or oxalic acid is almost always employed, whether the mordant mixed with the colour is perchloride of tin, protochloride of tin, or alum. At the same time, it is certain that even insoluble bodies, such as charcoal powder, often adhere firmly to wool, and dye it a durable and brilliant colour without undergoing solution. The most vivid colours on wool are generally obtained by protochloride of tin, with either oxalic or tartaric acid. To show the composition of the mixtures for such colours, a few examples may be given.

The *reds* for woollen stuffs are all formed with cochineal and preparations of tin. Thus for a poppy-red, take 1 gallon of cochineal liquor, made with 2½ lbs. of pulverized and prepared cochineal; thicken, hot, with 1¼ lb. of starch, and while still tepid add half a pound of oxalic acid, and 1 lb of a composition formed by adding 2 ozs. of tin to 9 ozs. of hydrochloric acid mixed with 5 ozs. of nitric acid.

For a *fine red*—boil for five minutes in 1 gallon of water 5 lbs. of crushed cochineal; thicken with half a pound of starch, and when the mixture has been well boiled, withdraw it from the fire and dissolve in it 1 lb. of oxalic acid and 10 ozs. of gum arabic; when cold, add 7 ozs. of chloride of tin at 106° Tw.

Steam-yellows for woollens are formed like the yellows for calico, by decoctions of Persian berry, quercitron, or weld, and have generally the oxide of tin along with alumina for their base. Thus, for an orange yellow, take 1 gallon of decoction of Persian berries at 14° Tw.; thicken with 2 lbs. of starch, and add to the mixture 10 ozs. of alum, 8 ozs. of chloride of tin, and 2½ ozs. of oxalic acid.

Two kinds of *blue* are in use for printing on woollen stuffs; the one formed with soluble indigo; the other with the ferrocyanide of potassium. Both have alumina for their base, and to promote its solution not only oxalic acid, but likewise a certain proportion of tartaric acid is introduced. To fix Prussian blue on wool, the red cyanide is decomposed by a suitable proportion of tartaric acid to set free the cyanide of iron, and a preparation of tin is added, the object of which is not so much to fix the colour, as to give it that fine shade known by the name of *royal blue.*

For a good *indigo blue*, dissolve in 1 gallon of warm water 5 ozs. of the soluble indigo of commerce; thicken with 3½ lbs. of gum, add 4 ozs. of alum, 5 ozs. of oxalic acid, and 3 ozs. of tartaric acid.

For a *Prussian blue*, in 1 gallon of water dissolve 12 ozs. of alum and 1 lb. of oxalic acid; thicken with 7½ lbs. of gum, then add to the tepid mixture half a pound of chloride of tin, 2½ lbs. of ferrocyanide of potassium, and 12 ozs. of nitrate of iron at 76° Tw.

Woollen goods are sometimes steamed at two operations, to prevent the flowing of the colours by a too prolonged exposure; but goods printed with detached figures are generally exposed to a single steaming of forty or fifty minutes' duration. The washing and dyeing of the woollen stuffs, after being printed and steamed, are two operations requiring some management. The ordinary washing machines soak the goods too much, and render the subsequent drying too slow. The best method is to subject the goods to a rapid wincing in a bath fitted with a reel like that of the ordinary dye beck, and capable of receiving a very rapid motion. The goods are then rapidly dried by means of the hydro-extractor.

DELAINES.—The printing *delaines*, which are formed of a mixture of cotton and wool, presents greater difficulty than is involved in the printing of either of the fibres separately. This will be obvious from the fact that the composition or mixture of the colours which is most suitable for cotton is less adapted for wool, and, on the other hand, the quantity of acids which is put into the colour mixtures intended for printing on pure woollens, would in many cases burn or injure the cotton fibre. There are some colours, also, easily fixed on wool, but which have very little adherence to cotton stuffs; and as a general rule it must be obvious that the greater attraction of the woollen fibre for the colouring matters must tend to create an inequality of shade in the colour or colours imparted to the two materials composing the printed stuff. The sulpho-indigotate of potassium, or soluble blue of commerce, affords a striking example of a colour which, when printed on delaines, communicates a strong shade to the wool, but only an imperfect coloration to the cotton contained in the fabric; and the mode in which this inequality is corrected will show how the difficulty is surmounted in most cases. It consists in mixing with the indigo blue for the wool a suitable proportion of steam blue for the cotton, prepared by a mixture of yellow or red prussiate of potash with tartaric, oxalic, or sulphuric acid, and alum. In one peculiar style of fancy dyeing, the woollen thread only is dyed, and the cotton is afterwards perfectly bleached by exposing the dyed delaines to a dilute solution of bleaching powder.

Delaines for printing are now generally prepared in the following manner:—After being thoroughly bleached the pieces are twice padded in stannate of soda, in a machine with wooden rollers. Next they are winced through sulphuric acid sours at 3° Tw., washed slightly, dried imperfectly, and then twice padded in sulpho-muriate of tin at 4° Tw.

The sulpho-muriate of tin is prepared by taking

Double muriate of tin at 120° Tw.,...	3 quarts.
Sulphuric acid, full strength,........	2 "

Mix gradually, and add an equal measure of ordinary muriatic acid at 32° Tw.

After padding the pieces are run at once into a large beck fitted with rollers, and containing chloride of lime solution at ½° Tw. They are then washed, whizzed, and dried. Just before printing they are padded in gum Senegal water, half a pound per gallon, and dried again.

The steaming is performed in the same manner as for woollens, and either by the column or chamber, but generally for three quarters of an hour only. This is a point, however, for which it is impossible to lay down any fixed rule, as the time must vary according to the manner in which the steam is applied, the dimensions of the chamber, and the quantity of acid in the mixtures. With a considerable quantity of acid, such as is best adapted for woollen stuffs, the fibres of the cotton especially become weakened by too long exposure.

As specimens of the colours used for delaines we may take the following:—

Black—

Logwood liquor at 12° Tw.,........	6 quarts.
Starch,.........................	1½ lbs.

Boil together, and when it has cooled down to 90° F. add—

Nitrate of iron at 86° Tw.,.........	1 pint.

Royal Blue—

Water,.........................	2 gals.
Starch,.........................	5 lbs.
Solution of red prussiate at 30° Tw.,..	2 gals.
Gum tragacanth water,.............	1 quart.

Boil and add—

Tin pulp,.......................	6 quarts.
Tartaric acid,....................	36 ozs.
Oxalic acid,......................	6 "

Add, when cold—

Yellow prussiate,.................	8 lbs.
Tartaric acid,....................	10 "

Brown—

Sapan liquor at 9° Tw.,............	2 quarts.
Berry liquor at 18° Tw.,...........	2 "
Archil liquor at 12° Tw............	1 "
Starch,.........................	1 lb.

Boil and add—

Alum,..........................	12 ozs.
Sal-ammoniac,....................	2 "
Verdigris,.......................	1 "

Chocolate—

Sapan liquor at 20° Tw.,...........	1 gal.
Nitrate of alumina,................	1 "
Logwood liquor at 30° Tw.,.........	3 pints.
Bark liquor at 30° Tw.,............	1 quart.
Ground gum,.....................	14 lbs.
Chlorate of potash,................	10 ozs.

Dissolved in—

Boiling water,....................	3 quarts.
Blue vitriol,......................	3 ozs.

Green—

Berry liquor at 12° Tw.,...........	2 gals.
Alum,..........................	1½ lbs.
Starch,.........................	3 "

Boil and add—

Ground yellow prussiate,...........	3 lbs.
Tin crystals,.....................	8 ozs.
Oxalic acid,......................	8 "
Extract of indigo (measure),........	37 "

Orange—

Bark liquor at 19° Tw.,	1 quart.
Starch,	10 ozs.
Water (measure),	25 "

Boil and add—

Cochineal liquor at 8° Tw.,	⅛ pint.
Tin crystals,	4½ ozs.

Pink—

Ammoniacal extract of cochineal at 10° Tw.,	1 gal.
White tartar,	2 ozs.
Alum,	8 ozs.
Gum,	4 lbs.

Scarlet—

Cochineal liquor at 12° Tw.,	1 gal.
Starch,	2 lbs.

After boiling add—

Oxalic acid,	2 ozs.
Salt of sorrel,	2 "
Pink salt,	4 "
Tin crystals,	4 "

Yellow—

Berry liquor at 10° Tw.,	2 gals.
Starch,	2 lbs. 10 ozs.
Pale British gum,	8 ozs.
Tin crystals,	14 "

Iodine Green—

Acetic acid,	3 pints.
Gum gedda solution,	6 quarts.
Solution of blood albumin (6 lbs. per gallon),	4 gals.
Arsenical glycerine, standard,	3 pints.
Iodine paste green,	2 quarts.

Violet—

Hofmann's or methyl violet, dissolved in spirit,	20 ozs.
White gum liquor (3 lbs.),	3½ quarts.
Blood albumin liquor (6 lbs.),	1 pint.

The delaines, after printing, are hung up to cool, steamed, and after steaming, washed, whizzed, dried at a steam heat, and hung for a day or two in a cool room. Preparatory to steaming a piece of grey calico, previously padded in a weak beck of sugar of lead and dried, is wound on the reel along with each piece of delaine, to absorb any sulphur compounds liberated from the wool, and prevent stains.

PRINTING ON SILK STUFFS AND CHALIS.—The printing of steam colours on silks is similar to printing on woollens, except that the acids must be used more sparingly.

The madder style is only partially applicable to silks. Red, blacks, and chocolates are produced by a method closely analogous to that applied to calico, the mordants being printed on, aged, and dunged, and the goods after dyeing being soaped and washed in the usual manner. Purples do not succeed.

Silks are generally, however, printed in the steam-style, in which the whites retain their lustre unimpaired. The pieces are first prepared by steeping about four hours in a weak bath of sulpho-muriate of tin, generally at 2° Tw. This mordant is less acid than that used for delaines, being prepared by dissolving 1 lb. of tin crystals in water, adding very gradually 1 lb. of sulphuric acid at full strength, and letting down with water to the strength required.

The silks before steeping are boiled for about two hours with neutral curd soap, to the amount of 1 lb. for every 4 lbs. of goods. After the treatment with sulpho-muriate of tin, the pieces are washed in pure water and dried. The colours are generally similar to those used for woollens, but they require less acid, and a less amount of thickening. None of the gum substitutes or artificial gums should be used in silk printing, as they leave a harsh feel. Steam is generally applied at a rather low pressure for about half an hour.

As examples of the colours for silks we give :—

Black—

Logwood liquor at 14° Tw.,	1 gal.
Starch,	10 ozs.
Gum,	1 lb. 10 ozs.

Boil, and when cold add—

Nitrate of copper (crystals)	10 ozs.
Nitrate of iron,	8 "

Blue.—The royal, logwood, and indigo blues are almost entirely superseded by the aniline blues, which show to the greatest advantage upon silks. The spirituous solution of the colour is thickened with gum Senegal water, at 3 lbs. per gallon, using more or less according to shade. No albumin or lactarine is required, as the colour has a strong affinity for silks.

Chocolate—

Sapan liquor at 12° Tw.,	1 gal.
Logwood liquor at 12° Tw.,	5 pints.
Dark liquor at 15° Tw.,	1 pint.
Sal-ammoniac,	12 ozs.
Alum,	1 lb.
Gum Senegal,	7 lbs.

Green, Dark—

Berry liquor at 14½° Tw.,	2 quarts.
Gum,	1 lb.

Dissolve and add—

Extract of indigo,	3¾ ozs.
Solution of tartaric acid at 36° Tw.,	2 "
Oxymuriate of tin at 80° Tw.,	1 "

In greens, however, the methyl and iodine greens have nearly superseded all others, as they retain their tone by artificial light. They are fixed by the process of SEVEZ, as given for cotton, but are much more satisfactory upon silk. If a yellow shade is required, picric acid may be added.

Orange (coralline)—

Coralline,	2 kilos.

Add soda lye at 10° B., enough to dissolve it; dilute with water, add proto-chloride of tin (double muriate) at 40° B., apply heat, and filter. The precipitate thus obtained is mixed with

Magnesia,	100 grms.
Oxalic acid,	260 "
Gum, ground,	2000 "

Water enough to make up 10 litres.

The whole is mixed well, heated, and strained. After printing it is then hung up for ten hours, and then steamed for thirty to forty-five minutes.

Pink—

Sapan liquor at 6° Tw.,	2 gals.
Ground gum,	6 lbs.
Bichloride of tin at 120° Tw.,	8 ozs.

The finest pinks, and light roses upon silks, are produced by means of saffranin, no mordant being required.

Purple—

Logwood liquor at 3 Tw.,	2 quarts.
Peachwood liquor at 3 Tw.,	2 "
Alum,	2 lbs.
White sugar of lead,	1½ "

Much superior purples and violets are obtained with the aniline violet, Hofmann's, Perkin's Britannia, the methyl, &c. For a so-called *dark primula* 1 pint of the solution of Hofmann's violet is let down with 20 pints of gum Senegal water, at 3 lbs. per gallon. For paler shades a proportionately larger volume of gum-water is taken.

Red—

Cochineal liquor at 4° Tw.,	1 gal.
Bark liquor at 12° Tw.,	½ pint.
Starch,	1 lb.

Boil, and after cooling add—

Oxalic acid,	5 ozs.
Tin crystals,	5 "

Magenta, Deep.—1 pint of Brock, Simpson, and Spiller's roseine (No. 2), and 6 pints of gum Senegal water (3 lbs.). For lighter shades increase the gum-water.

Scarlet—

Cochineal liquor (strong),	1½ gals.
Starch,	1 lb.

After boiling add—

Fustic liquor at 15° Tw.,	2 ozs.
Berry liquor at 15° Tw.,	2½ "
Salt of sorrel,	7 "
Tin crystals,	1¼ "
Bichloride of tin at 100° Tw.,	5¼ lbs.

Yellow—

Water,	2 gals.
Turmeric,	3 lbs.
Berries,	3 "

Boil down to 1 gallon, strain, and add—

Tin crystals,	¼ lb.
Alum,	½ "
Gum, more or less,	2 "

The steam-colours for chalis, or mixed fabrics of wool and silk, are necessarily similar to those applied to silks individually, because, if the acids were present in a free state, and in the same proportion with which they are mixed with wool colours, the texture of the silk in the fabric could not fail to be weakened. When this precaution is taken the printing of mixed fabrics of silk and wool, both of which are animal fibres and have nearly the same affinity for the colouring matters, is not attended with the same difficulty as that of delaines, or a mixture of wool and cotton.

Dyeing Processes.—Before proceeding to give a series of practical receipts for producing the various colours upon animal and vegetable fibres, and for the requisite subsidiary operations, a few general remarks will be useful.

Wool may be taken as the type of the animal fibres which come under the hands of the dyer. It contains nitrogen and sulphur, both of which have been supposed to play an important part in determining its relation to colouring matters. Its affinities for dyes, whether natural or artificial, are strong. Thus, it takes up without any mordant the bulk of the coal-tar colours, the preparations of archil, sulphate of indigo, &c. Even the so-called adjective colours, which require the aid of a mordant, stain it to a certain extent, though not with the fulness and body required to constitute a true dye. Wool is generally dyed in acidulated liquids, and at temperatures at or near 212° Fahr. But though little affected by dilute acids, it is readily injured by alkaline solutions, especially if hot; nor can it, as a rule, take up either mordants or colouring matters from alkaline solutions.

The principal mordants used in woollen dyeing are—alum, from which wool is able at a boiling heat to take a portion of alumina; bitartrate of potash (argol or tartar) is generally used as an adjunct to alum and the salts of tin, which it renders more easily decomposable by the fibre. The chromates of potash are very important mordants; and along with logwood and astringents form the greater part of the black dyes now used upon woollens. Iron is little employed as acetate or nitrate, but frequently as copperas. The preparations of tin used in woollen dyeing are chiefly protosalts; the protochloride, which in its different stages of concentration forms the single and double muriates of tin and tin crystals, being the chief. It is mixed in various proportions with sulphuric, tartaric, and oxalic acids, to subserve special purposes, and is sold under a variety of fanciful names.

Persalts of tin, commonly called oxymuriate, permuriate, nitro-muriate, and the like, are but little used by woollen dyers. The sesquisalt, known for want of a better name as nitrate of tin, is frequently employed, especially for scarlets and other cochineal colours. Here, more than in the case of cotton, the result of the coal-tar colours has been to diminish the scope for metallic mordants. The astringents, galls, catechu, sumach, &c., which play so important a part in cotton and even silk dyeing, have here no place. Mineral colours, properly so-called, such as chrome yellows, manganese browns, and iron buffs, are not employed in wool dyeing, and if attempted, give utterly unsatisfactory results. Even Prussian blues upon wool are produced, not by working the goods alternately in solutions of iron and of prussiate of potash (as in case of cotton and silk), but by heating in a solution of the latter substance in presence of an acid mixture known as "royal blue spirits."

Indigo is very extensively applied to wool in the vat. But the vats required for dyeing animal fibre are different in their composition from that used in cotton dyeing, and much more difficult to manage. The vats for wool are kept warm, whilst the cotton vat is worked at the ordinary temperature, and is hence spoken of as the "cold vat."

The affinity of wool for many colouring matters being very strong, there is often a difficulty in preventing them from working on to the fibre too quickly, and in consequence irregularly. To prevent this substances are added to moderate the excessive affinity of the colours for the fibre. Of these substances, known as "levellers," the sulphate of soda is the most generally useful. In some cases a level shade is obtained by the mode of manipulation. The pieces are made to pass through the dye beck with very great velocity. Sometimes also the entire amount of colour necessary to dye a given weight of materials is not put into the beck at once, but added by degrees, the goods being of course withdrawn from the liquid at every such addition.

The colours of woollens are generally expected to be faster and more permanent than those of cotton tissues. During the process of manufacture many woollens are exposed to the operation of fulling or milling—in principle, severe friction and percussion in concentrated soap-lyes. When they pass into the hands of the consumer, they are expected to retain their colour and lustre longer than cotton wares, whilst exposed to air, sunshine, damp, perspiration, and other colour-destroying influences.

Wool comes into the hands of the dyer in its unwashed state, as yarn, and as pieces. Each of these conditions necessitates variations in the plant and manner of working, and to some extent also in the mixture of the dye wares. Each of them also has its especial advantages and its peculiar difficulties. A large quantity of wool is dyed loose in its unmanufactured state, though freed, of course, from all grease and dirt. This kind of dyeing is performed in large fixed pans, which according to the colour to be produced, and the materials to be employed, may be made of iron, copper, or block-tin. Provision is always made for the application of heat, either by a small furnace directly beneath the pan, or by means of steam blown into the liquid by a pipe pierced full of holes. When steam heat is used, metal pans may be replaced by stone, slate, or wooden cisterns. The mass of wool is duly turned about in the liquid with the dyers' pole, no mechanical arrangement having been yet devised to supersede manual labour in this department. Each of the two methods of heating has its disadvantages. The open fire beneath the dye pan may char a portion of the wool or of the dye wares that come in contact with the sides of the pan, just above the surface of the liquid. On the other hand, a current of steam rushing into the pan or cistern may under certain circumstances produce a regular rotatory motion of the wool which promotes felting; in other words, which causes the fibres of the wool to adhere together in a compact mass, not to be separated without injury to the quality and great labour.

Wool dyeing is considered on certain grounds preferable to yarn and piece dyeing. Every fibre of the wool is brought equally and thoroughly in contact with the dye liquor, no part being shielded by others. Hence the shades produced, other things being equal, are more solid and permanent. Hence, especially for goods which are required to resist considerable wear and tear, wool-dyed qualities are in demand, and fetch a higher price. If wool-dyed cloth is cut, the section will show the same depth of colour as the outer surface, which is not necessarily the case in piece-dyed goods. Wool-dyed cloths, therefore, do not "wear grey."

On the other hand, wool dyeing necessitates extra care and expense in every stage through which it has to pass before leaving the hands of the manufacturer. It must not come in contact with any substance which would injure the colour, or would leave a stain that cannot be removed without inflicting an injury. Hence wool dyeing is more adapted for full dark shades and for permanent colours, than for light shades and fugitive colours. Wool-dyed goods are also less brilliant than such as are piece dyed. The more superficial a colour, the brighter it appears. This arises from the fact that no dye is absolutely opaque, and that the outer surface of a superficially dyed article is lit up by the light reflected from the white fibre below. But if the whole thickness of the tissue is thoroughly dyed, and every fibre saturated with colour, such a reflection of light cannot take place.

Rags and shoddy are dyed in the same manner as loose wool. The chief difference is that the former are not white, like new wool, but retain more or less the colours with which they have been previously dyed, and which it is often impossible entirely to remove. Two general methods prevail in rag dyeing. The rags may either be stripped of their former colour, as far as possible, by the alternate applications of soap-lyes, soda, and dilute acids, and then sorted out to be dyed such colours as they admit;* or the already existing colours may, without stripping, be converted into the desired shades. To give a sample instance of such a conversion, black rags, dyed with logwood and a salt of iron, may be converted into a claret by boiling with so-called "claret spirits," a solution of protochloride of tin. In this operation the tin cuts out the iron, and takes its place in the fibre, thus changing the colour from a black to a claret.

We may here suitably advert to the variable appetite of different samples of wool for colours and mordants. If it is found that a given sample of wool can be dyed to a required shade with a given weight of dye wares, it by no means follows that the same shade can be produced upon another sample with the same quantities. On the contrary, wool from a different breed of sheep, from a different soil or climate, will probably differ in shade, and possibly also in tone.† Hence woollen manufacturers who have a reputation for goods of some particular colour, and who have them dyed on their own premises, are careful to buy year by year the same growths of wool. On the other hand, a public dyer who takes in work from all quarters, finds himself constantly obliged to vary his dye wares in accordance with the changing quality of the wool.

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* For instance, an unremoved blue tint in rags would permit them to be dyed purple, violet, or crimson, but would utterly prevent the successful dyeing of an orange, scarlet, ponceau, or even *cerise*.

† The technical use of these words may need explaining. Blue varies *in shade* from one bordering on white to one scarcely distinguishable from black. It varies in *tone* according as it approaches violet on the one hand, or green on the other.

A large quantity of wool is dyed in the state of yarn. Wool and worsted dyed in this state are largely used for knitting and embroidery yarns, for carpets, for table covers, curtains, fancy waistcoatings and dress pieces, shawls, tartans, &c., having a pattern. Similar articles, however, consisting of a mixture of wool or worsted and cotton, and having a pattern of two colours only, can be piece dyed, as will be further explained below.

Yarn dyeing holds a middle place between wool and piece dyeing, the fibre being less readily and thoroughly penetrated than in the former, but more so than in the latter. Great care is requisite that no loose colour, capable of smearing, be left on the yarns. Otherwise the patterns produced by the loom are seriously damaged, the dark shades soiling the adjacent light ones.

The manipulations in woollen-yarn dyeing are simple. The hanks, secured on rods, are immersed in the dye liquids, and turned frequently to secure equal action on all parts of the yarn.

Piece dyeing is a style very extensively, and it may be said increasingly, used for a great variety of woollen cloths and worsted stuffs, such as doeskins, diagonals, merinos, camlets, serges, &c., not to speak of goods with cotton warps. It is generally considered the most economical method of dyeing, other things being equal. The wool can be spun and woven in the most expeditious manner, without any especial arrangements to escape soiling, and the pieces may then be cleaned once for all before being taken to the dye house. The great difficulty in piece dyeing is to insure a perfectly even or level shade over the whole of the piece. If in wool dyeing any small portion should take the colour either more or less readily than the rest, the defect disappears in the subsequent processes, by which the wool is thoroughly mixed up together; but in piece dyeing any part of the surface left darker or lighter than the rest is at once detected. Unevenness of colour may be occasioned by grease or any other kind of dirt, which acts as a resist, and prevents the colour from working on; by particles of aniline colours not thoroughly dissolved, and coming in contact with some portion of the piece; by the use of ill-prepared mordants; by immersing the goods in the dye beck without their being previously perfectly wetted out, or by entering them at too high a temperature, or allowing them to remain too long in one position, &c. Another difficulty, especially in thick goods, is to insure thorough penetration through the whole body of the piece. If this is not effected, and if the dye is deposited on the outer surface alone, it wears off where most exposed to friction. The plant required for piece dyeing consists of pans or becks, capable of being heated to the boiling point, and fitted with rollers, by means of which the pieces can be passed rapidly in and out of the liquid. Facilities for thus wincing at a high speed are very requisite, as promoting evenness of shade.

Garment dyeing may be considered as a branch of piece dyeing, from which it differs merely in the fact that the garment dyer, instead of working upon new white materials, operates upon old and worn tissues, upon which he is required to produce either their original colour or a new one. To obtain a level shade under these circumstances is often difficult, and sometimes impossible. For, even supposing that the garment to be re-dyed is perfectly freed from dirt and evenly stripped from the former colour, some parts of it will always be found to have been roughened in the course of wear more than others. Now, wherever such roughening or abrasion has taken place, there the colour will work on more heavily. On the other hand, the garment dyer has one great advantage: he does not ordinarily work to pattern. He is merely required to dye a garment sent him, *e.g.*, a good blue. The manufacturer's dyer, on the other hand, is called on to dye say 100 pieces blue, "as per pattern accompanying." If the result is darker or lighter, brighter or duller, more inclining to the violet or to the green than the pattern sent, he fails in giving satisfaction.

In woollen dyeing a peculiar complication arises from the presence of so-called "burls" or "birls." These are small portions of vegetable substances, bits of straw, down of seeds, and the like, which become entangled in the fleece of the sheep, and are not thoroughly dislodged by all the processes to which wool is submitted. Like all ordinary vegetable matter, their affinity for dyes is, as a rule, feebler than that of wool. They therefore remain colourless, or nearly so, when the cloth comes out of the hands of the dyer, and when numerous give it a spotty appearance. To deal with these blemishes four different methods may be adopted. The burls may be plucked out of the cloth with a kind of tweezers, an operation which if not very carefully performed is apt to damage the surface of the tissue. Or the spots are covered, by means of a blunt pen, with a peculiar preparation known as "burling ink," of which there are different kinds made to suit the colour of the cloth. The pieces are stretched out over a kind of frame in a well-lighted room, and the operation is performed by women known as "burlers." As soon as all the spots on one length of cloth have been covered and rendered invisible a fresh length is drawn on to the frame, till the entire piece has been gone over. Without great care on the part of the burler some of the spots are apt to escape.

A good burling ink should exactly agree in shade and tone with the cloth in question. It must not, when dry, leave a glazed shining spot on the surface, and it must have no action upon the colour of the wool.

Where the burls are very numerous, the whole piece is submitted to an especial dyeing process, adapted to vegetable fibre, being in fact treated as if it were a mixture of wool and cotton. To "burl-dye" black cloths the pieces are steeped in dilute nitrate of iron, and then in a beck of myrobalans or logwood, or both. In many places an especial quality of nitrate of iron, known as "burling iron," is made for this purpose. Its preparation is a matter of some nicety. It must contain no hydrochloric acid, or the iron will be deposited upon the wool. It must not contain an excess of free acid, otherwise the dye on the wool may be partially stripped, or at least altered in tone. But on the other hand, it must not be supersaturated or overloaded with iron, or the wool will contract rusty stains which are not easily removed without damage to the dye.

A fourth method of dealing with the burls consists in passing the wool, cleaned but not dyed, through very weak sulphuric acid, and afterwards exposing to a gentle heat. Under these circumstances the vegetable matter is charred and broken up, so as to be subsequently removed by washing without any marked damage to the wool. This method is much more generally employed in France than in England.

Alpaca, vicuna, goat's hair, and all other true animal fibres, are dyed substantially in the same manner as wool.

Silk, for dyeing purposes, is intermediate between wool and the vegetable fibres. Like wool it has a strong affinity for colouring matters, and can be dyed with the bulk of the coal-tar and orchella preparations without the intervention of a mordant. But it is less able than wool to bear the action of strongly acid mordants, and is in most cases dyed at temperatures below the boiling point. Like wool, it cannot be bleached by the action of chlorine and the hypochlorites, such as bleaching-lime, but turns yellow. It is also very readily injured by solutions of alkalies, in which, indeed, it may be readily dissolved. Its affinity for astringents and for iron is very great. By taking advantage of this circumstance the weight of black silks is fraudulently increased to more than 100 per cent. Weighted silks, it must be remembered, are very seriously modified both in their mechanical and their chemical properties. The fibre is deprived of its toughness and elasticity, and becomes brittle. Pure silk is almost incapable of decay under the influences of air and moisture, but weighted silk undergoes a process of eremacausis, or gradual oxidation, and moulders away. Sometimes, when lying in heaps in a warehouse, the absorption of oxygen has been so rapid that a great development of heat ensued, resulting in spontaneous combustion.

The preparation of tin mordants for silks was a matter of great nicety, the sesqui and persalts being preferred. But since the introduction of the coal-tar colours the scope for these preparations may be said to be at an end. For these colours no mordant is ordinarily required in silk dyeing. Indeed, one of the chief difficulties to be overcome in their application to silk was their excessive affinity for the fibre, which caused them to work on unevenly. This evil was overcome, at the suggestion of Mr. Perkins, by mixing the solution of the dye in a weak soap-lye. This moderates the affinity of the colour for the silk, and permits the production of level shades. If the resulting softness of the goods is objected to, they can be rendered hard, or as it is technically called, scroop, by passing it through very weak sulphuric acid, and then rinsing in pure water. All shades of reds, yellows, greens, blues, oranges, violets, as well as lavenders, doves, greys, &c., can now be produced upon silks with the coal-tar colours, as cheaply, and far more beautifully and simply than with the older dye wares.

Silk is dyed in three states—in the hank, in the piece, and as waste and rags. In all these conditions the plant and the manipulations are generally similar to those required in woollen dyeing. That a lower temperature is usual has been already mentioned.

Garment dyeing, or re-dyeing, on account of the high value of the material, plays a still more important part with silk than with wool. To re-dye the weighted silks now so generally sold is rarely practicable. They may be expected to break up on an attempt being made to clean them previously to dyeing.

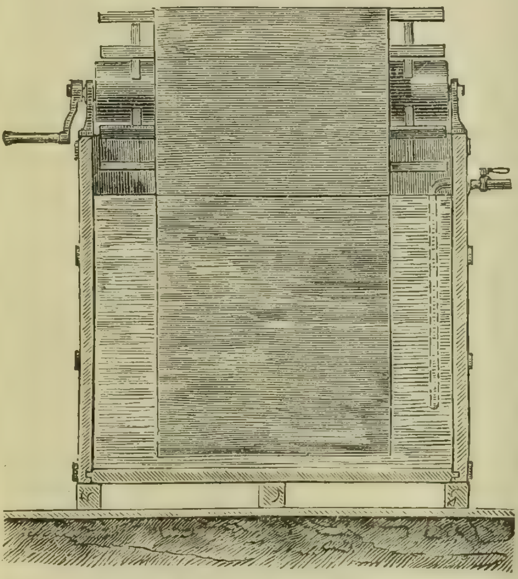
Cotton.—Of the vegetable fibres used in textile manufactures cotton may serve as the type. Its affinities for dyes are much feebler than those of the nitrogenous fibres, wool and silk. Hence, with few exceptions, of which carthamin is perhaps the most important, colours can only be made to combine with it by the intervention of mordants. Even with their aid several colours can only be deposited upon cotton to a slight extent, and in a very loose manner. Vegetable fibre is capable of bearing treatment with alkaline solutions of considerable strength, but it is easily damaged by acids. Hence cotton is generally dyed in neutral solutions. The application of a boiling temperature is rarely found advantageous. It is therefore dyed either cold, or at most at a so-called hand-heat. Cotton has a great affinity for tannin, as occurring in galls, sumach, myrobalans, divi-divi, &c. By being worked in in the extracts of these substances its affinity for many colours is greatly increased. It also combines eagerly with certain metallic oxides or subsalts. It is thus dyed black by successive working in an astringent and in a solution of iron; yellow by being alternately steeped in a solution of lead and in that of a soluble chromate. The mordants for cotton require to be nicely balanced, the base not being held in solution by an excess of any powerful acid. Thus, when alum or sulphate of alumina is employed in cotton dyeing, it is neutralized with carbonate of soda, until a permanent precipitate begins to appear. In this state the alum is enabled to yield up a portion of its alumina to the fibre. Very frequently, however, alumina is used for mordanting cotton in the state of acetate, known technically as red liquor. Acetic acid being much feebler than sulphuric, and being also volatile at common temperatures, parts more readily with its base. The chief compounds of iron used in cotton dyeing are the acetate, known also as black liquor, and the nitrate, more properly called nitro-sulphate. The crude sulphate of iron (copperas) and the chloride have comparatively limited applications. Various preparations of tin are also used in mordanting cottons. They are chiefly sesqui or persalts, and must be neutralized as far as practicable, or, as it is technically called, must be "well killed."

Lead compounds, such as the acetate and nitrate, are also used in cotton dyeing. They have been employed in fixing murexide and certain coal-tar colours upon the vegetable fibre, and more extensively in dyeing chrome yellows.

Lead and tin can also be used in cotton dyeing in alkaline solutions, as the so-called plumbate and stannate of soda. They yield their base to the fibre freely, and may be safely used for mordanting cotton unmixed with wool. If wool be present they are unsafe, as the sulphur which it naturally contains combines with the soda, and reacting upon the metal, causes a black or dark-brown sulphuret to be deposited upon the fibre, and thus stains the goods. Aluminate of soda is also occasionally used with a good effect in cotton dyeing.

Cotton is dyed sometimes as cotton wool, but generally in yarn (hanks), or when woven. The manipulation and the apparatus required are in general similar to those used in woollen dyeing. For cotton pieces, however, and especially for the cotton warps of mixed piece goods, such as delaines, &c., the mordants and colours are now generally applied by the aid of the padding machine. By this the solutions are mechanically pressed into the texture of the piece, and are thus enabled to penetrate the fibre, and combine with it more thoroughly and uniformly than could be effected by mere steeping or wincing in and out of the liquid.

Fig. 32.



The accompanying sketch, Fig. 32, however, shows an arrangement used in small dyeworks, which is fairly effective.

It must be noted as a distinctive feature in cotton dyeing, that the mordant and the colouring matter are not applied simultaneously, as is often the case in woollen dyeing, but in succession, the mordant first, and the dye afterwards. Were the two placed in the beck together, the general result would be the deposition of the colour not in or upon the fibre to be dyed, but as a lake or precipitate at the bottom of the beck.

Cotton garments, save when mixed with wool or silk, are rarely considered of sufficient value to be redyed. From a similar reason cotton rag dyeing is not a branch of tinctorial industry.

LINEN, China grass, jute, hemp, &c., are dyed, when requisite, on the same general principles as cotton.

MIXED GOODS.—The warp consisting of cotton or linen, and the weft of silk, wool, or alpaca, are dyed in the piece to an enormous extent. Sometimes it is required to produce in this manner a pattern of two colours, say, for instance, a scarlet design on a yellow ground. If the portions to be coloured consist of wool or worsted, they are dyed scarlet in the ordinary manner, which takes no effect upon the cotton. This is then dyed a gold-yellow with turmeric at a low temperature. In this manner a great variety of two-colour designs can be produced more easily than either by printing or by weaving the pattern with dyed yarns. Shot effects are also easily produced upon mixed goods of this nature. It is probable, however, that before long shot effects of a far superior character will be produced upon tissues of one kind of fibre only, by means of colours having the property of dichroism. Eosin is a dye which may be said to point in this direction, as it imparts to a thread or a woven fabric shades which vary according to the direction in which they are viewed.

In general, however, the object in dyeing pieces of mixed fibre is not to produce figures or shots, but to obtain a uniform colour over the whole surface. As a rule, the wool or worsted is dyed first at a boil, and the cotton afterwards in the cold, or at a hand-heat. Great care is required, and certain processes which would produce the shade required upon either the wool or the cotton singly are not admissible when the two are woven together.

Dyeing on Wool.—Indigo is fixed on wool by plunging it in an alkaline solution of indigo white, and then exposing it to contact with the air. The solution is prepared in a vessel usually from 8 to 9 feet in depth, and 6 or 7 feet in diameter, made of wood or copper, and bearing the name of *vat*. These vats are covered with wooden lids, divided into two or three equal segments, and covered over with thick blankets. Without this precaution the bath would be exposed to the atmosphere, and a portion of the indigo would absorb oxygen, and be precipitated.

A most necessary operation, and one of frequent recurrence, consists in agitating the deposit of vegetable and colouring matter formed in the vat, and intimately mixing it in the bath. For this purpose a rake, which is sometimes formed of a strong square piece of wood, set on a long handle, is employed.

Before the tissue is dipped into the dye bath, it is soaked in tepid water, and then hung up and beaten with sticks. In this state it is plunged into the vat, and thus introduces less air into the bath, while the fibre is more uniformly penetrated by the solution. The cloth is now kept in a depth of from 2 to 3 feet below the surface of the liquid, by means of an open bag or piece of network fixed in the interior of an iron ring, which is suspended by cords, and fixed to the outside of the vat by means of two small iron hooks; the bag is thus drawn backwards and forwards without permitting it to come in contact with the air. When this operation has been continued for a sufficient length of time, the cloth is wrung, and hung up to dry.

Flock wool, when dyed, is inclosed in a fine net, which prevents the least particle from escaping, and which is fixed in the bath in the same way as in the foregoing case.

In England iron vats are chiefly used. These are fixed in brickwork, which extends half way up their surface, whilst a stove is so constructed at this elevation that the flame shall play around their upper part. By this means the vat is heated, and kept at a proper temperature.

The potash vats are usually formed of conical-shaped coppers, surrounded by a suitable furnace. These may be constructed with less depth, inasmuch as there is less precipitation induced in the liquor. By using steam for heating the vats, the employment of copper vessels can be dispensed with, and those of wood adopted.

The vats employed for dyeing wool are known under the names of the pastel vat, the woad vat, the potash vat, the tartar lye vat, and the German vat.

The methods of dyeing by woad or pastel are given by DUMAS as follows:—

Pastel Vat.—The first care of the dyer, in preparing the vat, should be to furnish the bath with matters capable of combining with the oxygen, whether directly or indirectly, and of giving hydrogen to the indigo. These advantages are found in pastel and woad. Madder is used along with the woad.

The pastel vat ordinarily contains from 18 to 22 lbs. of indigo; 11 lbs of madder might suffice for this proportion, but the large quantity of water which has to be charged with oxidizable matters must be taken into consideration. Even 20 lbs. to a vat of this size have been employed, invariably with the best results. Bran is apt to excite lactic fermentation, and should, therefore, not be employed in too large a quantity; 7 to 9 lbs will be found amply sufficient.

Woad is rich in oxidizable principles, and putrifies with facility. Some dyers use it very freely; but in this bath an equal quantity of it to that of the bran is commonly employed.

In most dye houses the pastel is pounded before introducing it into the vat. The effect of the dye-stuff, when reduced to coarse powder, is more uniform; but this state of division must render its alterations more rapid. When the bath has undergone the necessary ebullition, the pastel should be placed in the vat, the liquor decanted, and at the same time 7 or 8 lbs. of lime added, so as to form an alkaline lye capable of holding the indigo in solution. The whole having been well stirred, it should be allowed to repose for four hours, so that the little pellets may have time to become thoroughly soaked, and thus be prepared for fermentation. Some thick coverings are to be spread over the vessel, so as to prevent contact with the atmosphere. After this lapse of time it is again agitated. The bath at this moment presents no decided character; it has the peculiar odour of the matters which are held in suspension and solution, and has a yellowish-brown hue.

Ordinarily, at the end of twenty-four hours, but sometimes after fifteen or sixteen, the fermentative process is well marked. The odour becomes ammoniacal, while, at the same time, the peculiar smell of pastel is easily perceived. The bath, hitherto of a brown colour, now assumes a decidedly yellowish-red tint. A blue froth, which results from the newly-liberated colour, floats on the liquor as a thick scum. A brilliant pellicle covers the bath; and beneath blue or almost black veins may be distinguished, owing to the indigo of the pastel having an ascendant tendency. If the menstruum be now agitated, the small quantity of indigo which is formed floats on the surface of the bath. On exposing a few drops of this mixture to the air the golden-yellow hue quickly disappears, and is replaced by the blue tint of the indigo. This phenomenon is due to the absorption of the oxygen of the air by the indigo white of the pastel. Wool might be dyed even at this juncture without any further addition of indigo; but colours furnished at this period are devoid of brilliancy and vivacity of tone, while the bath becomes quickly exhausted.

The signs above described announce in a most indubitable manner that fermentation is established, and that the vat has now the power of supplying to the indigo the hydrogen which is required to render it soluble, and this, consequently, is the proper moment for adding the pulverized indigo.

The ordinary guide of the dyer is the odour, which, according to circumstances, becomes more or less ammoniacal. The vat is said to be either *soft* or *harsh;* if the former is the case, it is requisite to add a little more lime. The fresh vat is always soft; it exhales a feeble ammoniacal odour, accompanied with the peculiar smell of pastel, and lime is therefore introduced along with the indigo—from 5 to 6 lbs. are usually employed—and after having stirred the vat, it is carefully covered. The indigo, incapable of solution except by its combination with hydrogen, gives no sign of being dissolved until it has remained a certain time in the bath. It may be remarked that the hard indigoes, as those of Java, require more than six hours for their solution. The vat should be again examined three hours after adding the indigo. The odour is generally by this time weakened; a further quantity of lime is again added, sometimes less, but mostly about equal in amount to the first portion; it is then re-covered, and again left for three hours.

After this lapse of time the vat will be found covered with an abundant froth, and a very evident pellicle of a coppery hue; the veins which float upon its surface are larger and more distinct than they were previously; the liquor becomes of a deep yellowish-red tinge. On dipping the rake into the bath, and allowing the liquid to run off at the edge, its colour, if viewed against the light, is a well-marked emerald-green, which gradually disappears, in proportion as the indigo absorbs oxygen, and leaves in its place a mere drop, rendered opaque by the blue of the indigo. The smell of the vat is strongly ammoniacal, but the peculiar scent of the pastel is at the same time discernible. When so obvious a character as this is found in the newly-formed vat, the stuff intended to be dyed may fearlessly be plunged in; but the tints given during the first working are never so brilliant as those subsequently obtained. This is owing to the yellow tinctorial matters of the pastel, which, aided by the heat, become fixed on the wool at the same time as the indigo, and thus communicate to it a greenish tint. This accident is common both with the pastel and the woad vats, though it is less marked in the latter.

When the goods have been immersed for about an hour in the vat they should be withdrawn; it would, in fact, be useless to leave them there for a longer time, inasmuch as no more of the colouring principle could be taken up. They are hung up to dry, when the indigo white, by attracting oxygen, becomes insoluble, and acquires the well-known blue colour. If the stuff be now again plunged into the vat, the shade will immediately become deeper, owing to renewed absorption of indigo by the wool. By repeating these operations very deep shades may be communicated.

The pastel in the foregoing mixture may last for several months; but the indigo must be renewed as it becomes exhausted, at the same time adding both bran and madder. In general the following proportions are employed:—

11 to 13 lbs. of good indigo for 100 lbs. of fine wool.

9 to 11 lbs. of good indigo for 100 lbs. of common wool.

9 to 11 lbs. of good indigo for 131 yards of cloth dyed in the piece.

Woad Vat.—These vats were extensively employed in the manufactories of the north of France. The bath is prepared in the same manner as for the pastel vat. The finely-cut woad is introduced into the copper along with 2 lbs. of pulverized indigo, 9 lbs. of madder, and 15½ lbs. of slaked lime. The liquor is, after the necessary ebullition, poured upon the woad. This substance contains but a very small quantity of the colouring principle; and some indigo must therefore be added when preparing the vat, so as to indicate the precise instant when the mixture arrives at the point of fermentation requisite for imparting hydrogen to the tinctorial matter, and for rendering it soluble. A large quantity of lime must also be employed, since the woad contains no ammonia resulting from previous decomposition. When the vat is in a suitable state of fermentation, a rusty colour becomes manifest, in addition to the signs already described in speaking of the pastel vat; besides the ammoniacal odour, the bath always retains the peculiar smell of the woad. The pounded indigo is now added, and the operator proceeds in the manner already detailed to reduce it to a state of solution fit for dyeing.

The vats prepared by means of pastel have greater durability than those made with woad; but it is thought that the colours given by the latter are more brilliant than those obtained from the former.

It must be understood that the pastel and woad vats are becoming more and more superseded by the vats to be described below.

The so-called Indian vat was till lately set as follows:—Add 8 lbs. of finely-ground indigo to a bath of water containing bran, 3½ lbs., the same weight of madder, and 12 lbs. of potash. Keep the mixture at 200° Fahr. for some hours, and then cool down to 100° Fahr., when fermentation sets in. In about forty-eight hours the indigo becomes soluble, having been reduced by the decomposition of the saccharine matter, &c., in the madder. The colour of the vat is of a greenish-yellow, more or less covered with a coppery scum.

The use of madder has now been abandoned on account of its expense. The present method is to add to water at 200° Fahr. 20 pails of bran, 26 lbs. of soda crystals, 5 lbs. slaked lime, and 12 lbs. indigo. The temperature is kept up for five hours, and is then allowed to fall to 100° Fahr., when fermentation and solution occur as before. These vats are generally of a conical shape, and are so fixed that a small fire can be maintained around them, or else the temperature is maintained by means of a steam jacket. The Indian vat requires renewing more frequently than the woad and pastel vats, from the indigo being more difficult to dissolve after a certain lapse of time. They should be maintained at a moderate temperature whilst working. They are more easily managed than the woad and pastel vats, the fermentation being much more under control and less liable to change its character.

Potash Vat.—This species of vat is extensively employed at Elbeuf for the dyeing of wool in the flock. It presents in all respects a perfect analogy with the Indian vat; in fact, the action of the tartar-lye in the latter preparation depends entirely on the carbonate of potash which it contains. The ingredients used in the preparation of the potash vat are bran, madder, and the potassium carbonate of commerce.

Deep shades are obtained in this species of vat with greater celerity than in all others, a fact which undoubtedly depends on the greater power which potash has of dissolving indigo than is possessed by lime. Experience proves that the potash vat has the advantage in point of celerity of nearly a third; but this is balanced by the inconvenience resulting from the darker shade, which must be attributed to the large quantity of colouring matter of the madder dissolved by the alkaline lye becoming fixed on the stuff with the indigo.

To obtain this vat in its most favourable state, the indigo should be made to undergo a commencement of hydrogenation before turning it into the mixture. For this purpose a bath analogous to that in the vat is prepared in a small copper, to which the pounded indigo is added. This bath is maintained for twenty-four hours at a moderate heat, taking care to stir it from time to time. The indigo assumes a yellowish colour, dissolves, and in this state is turned into the vat. Many delays and losses are thus avoided in its preparation; and, indeed, it would be desirable if a similar plan were adopted with all these compounds.

German Vat.—This vat is of nearly similar dimensions to that used for woad, being three times the size of the potash vat. Its diameter is about 6½ feet, and its depth 8½ feet. Having filled the copper with water, it is to be heated to 200° Fahr.: 20 pailfuls bran, 22 lbs. of carbonate of soda, 11 lbs. of indigo, and 5½ lbs. of lime, thoroughly slaked in powder, are then added. The mixture is well stirred, and left for two hours. The workman should continually watch the progress of the fermentation, moderating it more or less by means of lime or carbonate of soda, so as to get the vat in a working state at the end of twelve, fifteen, or, at the most, eighteen hours. The odour is the only test by which the workman is enabled to judge of the good state of the vat. He must therefore possess considerable tact and experience.

In the process of dipping, 84, 106, or even 130 lbs. of wool are introduced in a net bag, similar to that used in the woad vat, taking care that the bag is not allowed to rest against the sides of the copper. When the wool has sufficiently imbibed the colour the bag containing it is removed, and allowed to drain for a short time over the vessel. In this way two or three quantities are operated upon in succession. The vat is then left for two hours. The workman must be careful to replace the indigo absorbed by the wool, as also to add fresh quantities of bran, lime, and crystallized carbonate of soda, so as to keep the fermentation at a suitable point.

The German vat affords a remarkable saving as compared with the potash vat, but it requires great care and is more difficult to manage. It also economizes labour; one man is amply sufficient for each vat.

Management of the Vats.—A good condition of the vat is recognized by the following characters:—The tint of the bath is of a fine golden yellow, and its surface is covered with a bluish froth and a copper-coloured pellicle. On dipping the rake into the bath there escapes bubbles of air, which should burst very slowly; when they vanish quickly it becomes an indication that more lime must be added. The paste at the bottom of the vat, green at the moment of its being drawn up, should become brown in the air; if it remain green, this is a further sign that more lime is required. Lastly, the vat should exhale the odour of indigo. The operator usually completes the assurance of the vat being in a good state by plunging into it, after two hours' respite, a skein of wool, which, on being withdrawn after the lapse of half an hour, should present a green colour, but change directly to blue. The materials of the vat are then once more mixed, and two hours after it may be considered ready for dyeing.

The heat of the vat should never be allowed to fall below 130° Fahr. After each operation the bath must be well stirred and fresh lime added; generally speaking, 1 lb. a day will suffice; the indigo is re-established about every second day. When once this vat is well set, if the operator is careful to examine its working, from two to four batches a day may be dyed with it.

When the stuffs have acquired the desired shade, they are first to be washed in common water, and then in a very weak solution of hydrochloric acid, about 1 part in 1000; after this they are again rinsed in pure water.

When exposed to the influence of putrid fermentation indigo is decomposed and loses its colour. If rendered soluble, it obeys the impulse communicated to the nitrogenized matters with which it is brought into contact, although, if macerated in pure water at the ordinary temperature, it is itself decomposed with great difficulty.

Pastel and woad are very prone to the putrid fermentation, on account of the large quantity of nitrogenous matters which are contained in them; they require, therefore, considerable care in their employment.

When a vat is set, if the fermentation be allowed to continue unchecked, after the appearance of the blue froth and the other signs already indicated, the liquor will acquire a yellow colour similar to that of beer; the froth will become white; it will give out a stale smell and lose its ammoniacal odour; after a few days it will turn whitish, and exhale a smell at first similar to that of putrid animal matter, then it will acquire the smell of rotten eggs, and set free sulphuretted hydrogen. The lime in the pastel and the woad vats, and the tartar-lye and potash in the other mixtures, are used for the purpose of preventing these accidents.

Besides the oxidized compound which is formed by the combination of oxygen with the extractive matters, there is a production of carbonic acid which saturates the alkaline lye, and forms a carbonate of lime in the pastel vat. This is found attached to the sides of the vat in such quantity that the inside of these vessels becomes encrusted with it to a considerable depth. If a piece of woollen tissue be plunged into a vat which has been recently stirred it will acquire a dark colour, and will be found covered with brown stains, which are with difficulty removed. When the woad or pastel vat has been stirred it need be left two or three hours only before plunging in the stuff, at least during the early months of its working, inasmuch as the pastel, being but slightly divided and attenuated, is readily precipitated; but when, by reason of its extreme division in consequence of repeated operations, it is thrown down with less facility, the dipping should not be performed oftener than three times in the day.

The Indian vat requires less time than the others; it may be used an hour after stirring the mixture. The potash being soluble, forms no precipitate; while the fibre of the madder and the pellicles of the bran become deposited with great facility. One can also dip with these vats much oftener than with those made by pastel or woad.

Cotton Vat.—The common blue vat for the dyeing of cotton is made up as follows:—The indigo is first ground in water to an impalpable paste, of the consistence of cream. A quantity of this paste is put into a vessel of water, and a quantity of copperas and slaked lime added, the latter in excess. The whole is well mixed by the rake. When cotton is dipped into this solution, the fibres become filled with white indigo. When lifted out and exposed to the air, the white indigo imbibes oxygen, and becomes converted into blue indigo within the fibre, and constitutes the dye—a beautiful example of chemistry applied to art.

The following vat, based upon a novel principle, has been proposed by Messrs SCHÜTZENBERGER & DE LALANDE, and has given very satisfactory results upon the large scale:—

A cask, capable of being closed at top so as to exclude the air, is filled with loosely lying feathered zinc, upon which is run a solution of bisulphate of soda at about 30° BEAUMÉ (= spec. grav. 1·26 to 1·30). Here it is allowed to stand for about an hour, and it is better to agitate occasionally by means of suitable machinery. The liquid is then run off into milk of lime, which throws down all the zinc that is in solution. After thoroughly stirring, the whole is allowed to settle, and the clear liquid is drawn off for use. The greatest care must be taken during all these processes to avoid any needless access of air. The clear liquid thus obtained contains hyposulphites of soda and lime. To it is now added finely ground indigo, and enough milk of lime to dissolve the reduced indigo and form a yellow solution, which contains no insoluble matter except what was present as impurities in the indigo. 1 lb. of indigo may thus be dissolved in 4 to 6 quarts of liquid.

For use the vat is filled with water, the solution of indigo is added in quantity, according to the shades required, and the dyeing can be at once begun. Cotton is, as usual, dyed in the cold, and wool and silk at about 80° to 90° Fahr. The vat must be kept slightly alkaline by adding from time to time a little milk of lime. If an addition of lime is needed, the vat looks black instead of a greenish-yellow. If too much lime is present, the wool will be hard, and the indigo will be fixed very loosely upon the fibre. This evil may be corrected by the cautious addition of a little dilute sulphuric acid.

Some practical authorities recommend the following modification of the proportions given above: 100 litres of bisulphite of soda at 5° B., poured into an air-tight stirring cask along with 7 lbs. of zinc powder, and agitated for twenty minutes. Of the clear liquor, 40 litres are taken to 1 kilo. ground indigo, and heated to 60° C.; 1 or 2 litres of milk of lime are added, and if needful a few litres more hydrosulphite till the mixture is a fine yellow.

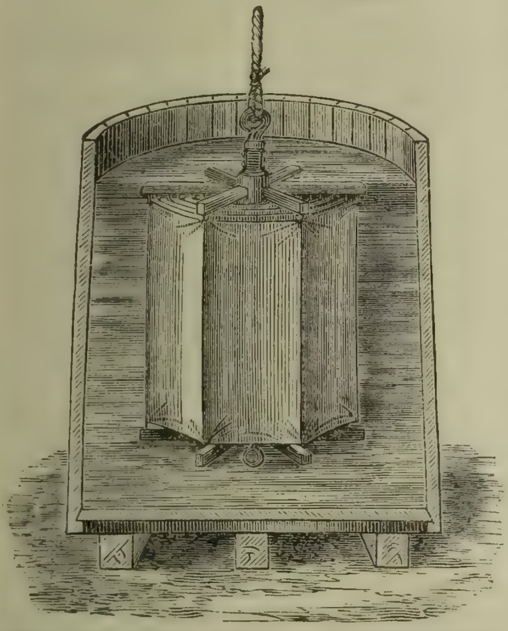
LEUCHS, of Nuremberg, employs as reducing agents in the indigo vat, pectose, pectine, and pectic acid, which may be had in the greatest quantity in turnips. He heats 200 lbs. soda-lye, of spec. grav. 1·35, to 170° Fahr., and adds 2 lbs. of indigo ground to a pulp. In the liquid he then suspends a wire basket containing from 30 to 40 lbs. of sliced turnips, and raises to a boil, air being as far as possible excluded. The cold liquor thus obtained is then mixed with 4 gallons water, and is ready for use: 9 lbs. turnips reduce 1 lb. indigo.

The vats used for dyeing cotton cloth are similar to those used for woollen and silk; but as no heat is required, they are sunk in the ground to a depth convenient for the operators to work at. This size of vat is also used by some for dyeing yarn, but more generally wine pipes or other large casks are employed for this purpose. Five vats constitute a set, and are worked together and kept of the same strength. The yarn being wrought in quantities of 100 lbs., 20 lbs. are passed through each vat. These vats are made up as follows:—Each is filled about three-fourths with cold water, and there is then added 8 lbs. indigo, 16 lb. sulphate of iron (copperas), and 24 lbs. newly-slaked lime. The whole is well stirred with the rake for half an hour, and this is repeated every hour and a half for the first day. The time to stop this agitation is known by the solution becoming of a rich oak-yellow, having large blue veins running through it, and a fine indigo froth on the surface. When these signs are all favourable, the vat is allowed to stand for several hours till all the solid matters settle, when it is ready for use. The reason for employing such deep vessels for vats is to allow room for the collection of the precipitate formed by the sulphate of lime and sesquioxide of iron, which, were they to touch the goods, would deteriorate the colour. The mode of dyeing by this vat consists in simply immersing the goods, and working them in the liquor for fifteen minutes, taking out and wringing or pressing, and then exposing to the air. If the tinge is not sufficiently deep by one immersion or dip, this operation is repeated, but generally in a different vat, and so on until the required depth is obtained. The practice is to begin the dye in the weakest and oldest vats and finish in the newest and strongest, which gives the finest bloom as a finish. All the liquor pressed or wrung out from the goods is put back into the respective vats, and when the operations are finished the vat is raked and allowed to stand till next day. The yarn is well washed in cold water, and then dried. In some cases it is passed through a tub of water acidulated with vitriol till it tastes acid, and then washed, which adds a little brilliancy to the colour when the shade is very deep, and tends to remove some of the iron which may have been fixed upon the fibre.

The quantity of liquid in one of these vats may amount to 100 gallons, so that, by keeping the proportions stated, any quantity of dyeing solution may be made up. Sometimes, from defects in the materials, such as impurities in the indigo, lime, or copperas, or from other causes, the exact appearances stated may not come up satisfactorily; but a very little practice will enable the operator to vary the process, or add the proper ingredient, so as to produce a good vat. This is a matter, indeed, depending more on experience than on any instructions that can be given. If the indigo is of inferior quality a greater quantity will have to be used. If the sulphate of iron is new and watery, not only more of that substance, but the addition of lime will be necessary; and if the lime is not newly slaked it may not be found very effective, as lime that has stood for some time absorbs carbonic acid, and is thus deteriorated for the vat.

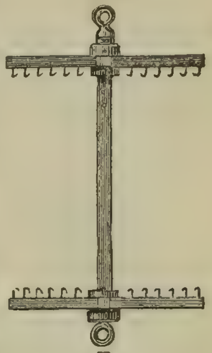
Figs. 33, 34, and 35 depict a very convenient apparatus for dyeing cotton with indigo. The calico is attached by hooks to the frame shown in elevation in Fig. 34 and plan in Fig. 35. This frame is attached to a rope, as in Fig. 33, and by means of a pulley is, when loaded with cloth, dipped into the indigo beck. After eight or ten minutes immersion it is withdrawn, and the cloth exposed to the air for a few minutes to blue it, and then again plunged in the dye beck. It is finally washed with much water.

Fig 33.



MINERAL DYES AND MORDANTS.—ALUM.—Alumina has a strong attraction for organic colouring matters, and hence is used for fixing them upon fabrics; but in order to have the alumina fixed within the fibres of the stuff to be dyed, it must previously be obtained in solution, and this can only be effected by converting the alumina into a salt; hence the dye produced may be, and generally is, not the pure tinctorial matter adhering to the alumina, but in the state in which it is changed and fixed by the salt, the acid element of which acts an important part in altering the tint of the colour. Thus, pure alumina put into a decoction of logwood will become deeply coloured, but the shade of the hue will be different from that obtained by putting into a similar decoction a solution of alum or acetate of alumina. Even the tints obtained by these last two mentioned substances will differ from each other. This is a circumstance which the dyer must ever bear in view, in regulating his tints either by mordants or alterants; and it is this chemical affinity of the colour with the salt of the base that renders it so essential to good results that the mordant, whatever it may be, should be perfectly pure. Alum containing the slightest trace of iron is unsuitable for general use in a dye house.

Fig. 34.



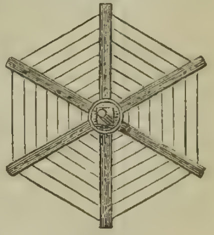


Fig. 35.

Alum is prepared for the dye house by simply dissolving it in water. About 1 lb. of alum to 1 gallon of water makes a good solution. It is not much used as a mordant for cotton, in consequence, doubtless, of the strong attraction which sulphuric acid has for alumina; but it is extensively used in dyeing both silks and woollens, the fibres of which seem to act more powerfully in retaining and fixing the base.

Very nice shades of lavender and lilac may be dyed by making a strong decoction of logwood, and adding to it 1 lb. of alum to 1 lb. of logwood. After standing for a day the cotton is wrought in this solution and wrung out. Light shades are dyed by adding some of this liquor to hot water, working the cotton in it for a time, and then finishing. This preparation is known as the "alum plum tub," or "lavender liquor." It is principally used for light cotton cloth.

Alumina, dissolved in acetic acid, is extensively used as a mordant for cotton in various processes of dyeing, and is known in the trade as "red liquor." The processes for its preparation, and the different results obtained, have already been described under *Acetate of Alumina*, to which the special attention of the dyer is called. The modes of using it will be referred to under the particular processes in which its use is required.

ARSENIC.—This metal and its oxides have been already described. Except as a test, it is not very extensively employed in the dye house. The principal use to which it was formerly applied was for dyeing what are technically called "arsenic sages," the colouring principle of which is SCHEELE's green, dyed by working the cotton through an arsenite of sodium or potassium, and sulphate of copper.

CHROMIUM (atomic weight, 52·2; symbol, Cr.)—This metal was first discovered by VAUQUELIN in 1797. It derives its name from its compounds being all of a brilliant colour, but as a metal it resembles cast iron in appearance. Hitherto, however, it has only been obtained in the state of a powder. It is very difficult to fuse, and is not subject to oxidation when exposed to the air. It resists the direct action of common acids—sulphuric, hydrochloric, and nitric. It is found native in considerable quantities in combination with lead and iron. The latter combination, termed chrome iron ore, is its principal source, and is found in America, in different parts of the continent of Europe, and in Scotland. The general composition of the ore is one portion of oxide of iron and one of chromium sesquioxide, or chromic oxide, Cr_2O_3.

It is capable of combining with two portions of oxygen, forming—

Sesquioxide, ... Cr_2O_3
Chromium trioxide, ... CrO_3.

The latter oxide in combination with water forms chromic acid, $HCrO_4$. The sesquioxide is a beautiful green-coloured compound, and is generally obtained from the decomposition of the acid by processes about to be described.

The acid is a brilliant scarlet-red coloured compound, and is prepared directly from the chrome ore by crushing the ore very fine, mixing it with a quantity of dried nitrate and carbonate of potassium, and then subjecting the whole to a strong heat in a reverberatory furnace. In this case the nitrate of potassium is decomposed, supplying oxygen to the chromic oxide, which is thus converted into chromium trioxide; and this combines with the alkali, forming chromate of potash, which is afterwards dissolved out by water. This chromate is then converted into the bichromate by the addition of acetic acid, which takes up half of the potassium. The bichromate is next crystallized from its solution, and constitutes the beautiful red-coloured salt so extensively used in dyeing, and known in the trade as "chrome."

The modes of preparing these salts, with the later improvements introduced, will appear under the article Potassium and its Salts. Reference will here be made only to the uses and applications of the bichromate in dyeing. The introduction of this salt into the dye house effected a complete revolution in certain departments of the art, and it still continues to make inroads upon old processes by new and more extensive applications. Its first use was the production of yellow with the salts of lead. By passing the goods through a solution of acetate or nitrate of lead, and then from that through a bath of bichromate of potash, a beautiful yellow is obtained, but some free nitric acid is accumulated in the chrome solution. The same kind of reaction takes place with acetate of lead, and this not only induces a strong tendency to change the shade of colour, but is hurtful to the fibre, while at the same time the process is not economical. These circumstances produced a variety of improvements, which consisted in first converting the lead salt into a subsalt, where two proportions of lead were in combination with one of acid, which met one of the difficulties.

In the dyeing of green, where the cotton was first dyed by the blue vat, as already described, and then dyed yellow, the free acid had a very prejudicial effect upon the indigo; hence it was one of the most difficult dyes to produce of an equal tint. The subsalt of lead did away with this difficulty to a certain extent; but the solution of lead upon the fibre, mixing with the chrome, caused a great precipitation of chromate of lead, producing a rusty colour and a loss of material; and consequently different solutions of lead were used, and also different matters put into the solution of chrome, which, after these remarks, the reader will be able to appreciate by the processes appended to this article for dyeing yellows, &c.

Shortly after the introduction of the chrome yellow dye, the dyeing of orange by the same salts came into practice, and was effected as follows:—A strong deep yellow was dyed upon the cotton; after which it was passed through lime-water brought nearly to the boiling point. This produced chromate of lime and subchromate of lead, which latter possesses a rich orange hue.

The different improvements effected in the dyeing of yellow have been adopted for orange. The object aimed at, with a view to the effective dyeing of this colour, is to obtain a large quantity of chromate of lead fixed upon the goods, so as afterwards to produce a rich orange. The formation of subsalts of lead, by boiling the acetate of lead with litharge, has consequently been largely practised for the dyeing of this colour.

Bichromate of potash is also extensively used, along with catechu, for dyeing browns, fawns drabs, and a great variety of other shades upon cotton. It has of late been much employed in dyeing woollens several shades of browns, blacks, drabs, and slates. With this fabric it acts the part of a mordant, probably by the chromic acid being reduced to the state of chromic oxide (Cr_2O_3).

Some dyers reduce the chromic acid into the state of chromic oxide previous to using. The following method has been recommended for effecting this reduction:—Dissolve 9 lbs. of bichromate of potash in 5 gallons of boiling water; then put 10 lbs. of arsenious acid into a boiler containing about 25 gallons of water; boil for a quarter of an hour, and allow the liquor to settle; decant the clear portion into a large vessel while the liquor is still hot, and then add to this clear solution the solution of bichromate of potash, stirring all the time; allow the whole to stand till perfectly cold. It is now put through a filter, upon which is collected the sesquioxide of chromium as a beautiful green-coloured precipitate. This oxide is soluble in hydrochloric acid, and may be used as the dyer finds it convenient, either as a mordant or otherwise. The method of dissolving it in hydrochloric acid is to dilute the acid with water until it no longer gives off fumes; it is then heated, and when hot as much of the sesquioxide of chromium is added as the acid will dissolve; the whole is then left to settle, and the clear portion is decanted. Any free acid which may still remain is neutralized by adding gradually a solution of carbonate of soda until the chromic oxide begins to be precipitated. The solution thus prepared has a dark-green colour.

This oxide is not much used for cotton, although some beautiful light drabs can be produced by a mixture of this solution with carbonated alkalies; and a variety of shades, varying from blue-black to grey, may be obtained by working cotton in the above-neutralized solution of chromic oxide and then adding a decoction of logwood. The strength of the solution and logwood must be regulated to suit the depth of colour and the particular tint required. The appended receipts will serve to illustrate the use and value of chrome as a dyeing agent, premising that the quantities given are for dyeing 10 lbs. weight of cotton. Of course the operator may either enlarge or reduce the proportions, according to the quantity of goods to be dyed:—

Light Straw.—To a tub of cold water add 4 ozs. of acetate of lead, previously dissolved; work the goods through this for fifteen minutes, and wring out; into another tub of water add 2 ozs. bichromate of potash; work the goods through this ten minutes, wring out, and pass again through the lead solution for ten minutes; wash, and dry.

Lemon Colour.—Into a tub of cold water put 1 lb. of acetate of lead, previously dissolved; work the goods in this for fifteen minutes, and wring out; into another tub of cold water put 6 ozs. bichromate of potash in solution; work the goods for fifteen minutes through this, and wring out; then put back, and work ten minutes in the lead solution; wring out, wash, and dry.

Deep Yellow.—To a tub of cold water add 1 lb. acetate of lead and 1 lb. nitrate of lead in solution; work the goods in this for half an hour, and wring out; then in a tub of warm water add 12 ozs. "chrome," and work the goods from the lead through this for fifteen minutes; expose to the air for half an hour, then pass again through the lead and chrome, working the same time in each as before, and allow an hour's exposure out of the chrome the second time; then pass through the lead; wring out, wash, and dry. If not deep enough, a third dip may be given, observing the same rules.

Deep Amber Yellow.—Put into a tub of water 1 lb. acetate of lead, and to this add gradually caustic potash or soda until the precipitate formed be re-dissolved, taking care not to add more alkali than is required for this solution. The goods are then wrought through this for half an hour; wring out, and then add 8 ozs. chrome in another tub of water, and work the goods in this for fifteen minutes; wring out, wash and dry. 2 or 3 ozs. of sulphate of zinc may be added to the chrome solution with good effect. If a red deep amber be required, add to the chrome solution half a pint of muriatic acid.

Chrome Green.—Dye a blue by the vat already described; then, on the top of the blue, dye a yellow, by the last receipt. Of course the depth of blue and yellow will regulate the tint of green, so that the proportions named for the yellow may be smaller, and the dips or immersions repeated more or less frequently, as required. The principal difficulty is when a particular depth or shade of green is wanted, to ascertain the exact shade of blue to be given, as blue cannot be added upon the yellow. This is a matter, indeed, which can only be learned by practice; but a very short experience will suffice.

A few receipts are annexed for dyeing with bichromate of potash upon woollens, the quantities stated being for 5 lbs. of woollen, either in thread, cloth, or wool. It ought to be premised that the woollen must always be well cleaned before dyeing, and that the dyeing must always be performed at a boiling heat:—

Black.—Work for an hour in a bath with 8 ozs. bichromate of potash, 6 ozs. alum, 4 ozs. fustic; lift, and expose to the air for a short time; wash well, and then work for an hour in another bath with 4 lbs. logwood, 4 ozs. barwood, 4 ozs. fustic; lift, and add 4 ozs. copperas in solution; work half an hour in this, and then wash and dry.

Blue-Black is first dyed blue by vat, or by ferrocyanide of potassium, or *yellow prussiate*, as will be afterwards described, and then proceeded with as directed in the above receipt, only using less materials.

Fast Lavender.—The following dye for wool is highly recommended:—For 150 lbs. wool, take 3½ lbs. bichromate of potash and dissolve in sufficient water, in which boil the wool for an hour. In another pan put 8 lbs. logwood and 4 lbs. cudbear loose, and boil them for a few minutes; then enter the wool, and boil for an hour. Finish by adding 1 quart oxalate of tin to 2 gallons water, and add this by degrees, stirring all the time.

Brown.—Work for half an hour in 8 ozs. of chrome; lift, and expose till cold; then into a new bath work an hour in 2 lbs. fustic, 4 ozs. madder, 3 ozs. cudbear, 4 ozs. tartar, 2 ozs. logwood; lift out, and dry; or it may be washed before drying.

Rich Yellow Brown.—Work for an hour in the following bath:—2 ozs. bichromate of potash, 2 ozs. argol, 2 ozs. alum; wash from this bath; then work for about forty minutes in another bath made up with 2 lbs. fustic, 1 lb. madder, 8 ozs. peachwood, 4 ozs. logwood; wash out of this, and dry. This gives a very beautiful brown; and a great variety of tints and shades may be made by varying the quantities of the last bath with the same preparation as the first bath.

Rich Yellow.—Work for half an hour in a bath with 3 ozs. chrome, 2 ozs. alum; lift, and expose till well cooled and drained; then work for another half hour, without previous washing, in another bath with 5 lbs. fustic; wash out, and dry.

Bottle Green.—Work for an hour in a bath with 2 ozs. chrome and 4 ozs. alum; lift out, and expose to the air for some time till the goods are cold; then work for an hour in a second bath with 3 lbs. fustic, 1½ lb. logwood; wash out, and dry.

Invisible Green.—Work for an hour in a bath with 3 ozs. chrome, 4 ozs. alum; lift, and expose to the air for some time; then work for an hour in a second bath with 2 lbs. fustic, 3½ lbs. logwood; wash out, and dry.

By comparing these two last receipts it will be seen that the different shades are produced by varying the proportions of the same stuffs.

Olive.—Work for an hour in a bath with 4 ozs. chrome, 2 ozs. alum; lift, and expose for some time to the air; then work for an hour in a bath with 3 lbs. fustic, 1½ lb. camwood, 1 lb. logwood; lift out, and dry.

Purple.—Work the goods half an hour in a bath with 1 oz. chrome, 1 oz. alum; lift out, and wash in cold water; and then work half an hour in a bath with 2 lbs. logwood, 1 lb. peachwood; lift, and add 1 oz. of alum in solution; work in this for twenty minutes; wash, and dry.

If a light and redder shade be required, use less logwood and more peachwood; and if a darker shade, more of each.

Rich Green Drab.—To the dye bath add 1 oz. bichromate of potash, half an oz. alum, half an oz. tartar, and work the goods in this half an hour; lift out, and wash through cold water. Make up a new bath of water, and add 4 ozs. logwood, 2 ozs. fustic, 1 oz. barwood, or half an oz. peachwood; work the goods again through this second bath half an hour; wash, and dry.

Shades of this can also be varied by using different proportions of stuffs.

Rich Drab.—Dissolve half an oz. of bichromate, and add the required quantity of water; work in this for half an hour; lift the goods, and add half an oz. of logwood; work again for half an hour; lift out, wash, and dry.

Different shades of this drab may be made by varying the quantities of the dyestuffs.

These receipts might be greatly multiplied; but those which have been given will serve as a guide for practice, and will sufficiently illustrate the extensive use to which bichromate of potash has been applied in dyeing. These directions are also so simple and easy, that even an amateur may put them in practice without risk of failure. The quantity of water to be used is immaterial; this will be regulated according to the size of the vessel, and the number of goods to be dyed; but there should always be enough of water to cover the goods without the necessity of pressing them down. Rules for making up decoctions and other manipulations will be given at the end of this article.

A great variety of effects are produced by the use of the neutral or yellow chromate of potash, of the acetate of chrome, and of chrome alum. The acetate of uranium also produces pleasing grey shades with extracts of madder, commercial and artificial ultramarine.

COPPER SALTS.—These are not very extensively used in dyeing. They have a peculiar influence in many operations, from their property of yielding oxygen, and thus, for many purposes, they act a very important part, well known to practical men, but not yet easily defined on scientific principles. They are very little used in the dyeing of cotton goods.

Sulphate of copper is used among catechu for destroying the gummy principle in that drug; it is also employed with copperas for certain tints and shades of black and brown upon cottons and woollens.

IRON SALTS.—*Copperas.* An important application of sulphate of iron has been already referred to when treating of the common blue vat. The quality of copperas used for this purpose is a highly important consideration. There is a watery-looking pea-green coloured crystal very common in the Scotch market, and which is not a good copperas for the blue vat. When tested, it invariably exhibits a deficiency of iron, and a higher proportion of acid than theory allows; and when such copperas is used for a vat, a greater quantity of it is required, and also more lime. The precipitate in the vat takes a much longer time to subside, producing what is technically termed "swimming," which affects the dye, and is an annoying circumstance to the dyer. The copperas best suited for the blue vat should have a dark rusty-green colour, and care should be taken that it contains no impurities, such as copper, zinc, or alumina, as the presence of these matters neutralizes the effects of iron in reducing the indigo.

The dyer should be acquainted with the means of testing the quality and value of his ingredients. The following are a few simple rules for copperas:—Dissolve 100 grains of the crystals in 4 ozs. of distilled water in a glass or china vessel, add to the solution one quarter oz. of nitric acid, and bring the whole to ebullition; this converts the iron to the state of sesquioxide. Divide the solution into four equal parts. To one part add an excess of caustic potash, and boil for ten minutes; pass the whole through a filter, and fill the filter several times with water to wash the precipitate, which may afterwards be thrown away. To the clear solution add sulphuric or hydrochloric acid until it reddens blue litmus paper; then add ammonia till the solution smells of that liquid, and allow it to stand over for half an hour. If a white precipitate appears, either immediately or after standing, then alumina is present, and the copperas should not be employed for the blue vat.

To another part of the original solution add ammonia in excess, and filter, washing the precipitate as before; but this precipitate is not to be thrown away. If copper be present the solution will have a bluish tint, and the copperas should not be used for the vat; if no blue tint shows itself, and no alumina, dry the filter with the precipitate, and then burn the whole at a red heat for ten minutes, or until the filter is all consumed; sesquioxide of iron remains, and this must be carefully weighed; then, as eighty of this is equal to seventy-two protoxide of iron (ferrous oxide), so will the weight of the residue obtained be equal to the protoxide originally in the copperas; and the quantity of the solution being a fourth of the 100 grains, the result is multiplied by four for the percentage.

The following is the theoretical composition of copperas:—

Ferrous oxide,	25·9
Sulphuric acid,	28·8
Water,	45·3
	100·0

So that, if the quantity of ferrous oxide be less than 26 per cent. the copperas is inferior; it ought to be nearer to 27 for good old copperas.

To the third portion of the original solution add a solution of chloride of barium, so long as there is any precipitate formed, and allow it to stand for half an hour; then filter, and wash the filter till a little of the water passing through, caught in a clean glass, gives no precipitate with sulphuric acid; when thus washed the filter with its contents is dried, and then burned in the same way as the iron precipitate; the remainder is weighed, and calculated by this equation:—As 116 sulphate of barium is equal to 40 sulphuric acid, so is the weight obtained to the sulphuric acid present in the copperas; the result multiplied by 4 gives the percentage, which should not exceed 29 per cent., as given above. If, as is often the case, the result be 30 per cent., there is something wrong.

Copperas is extensively used in the dye house for a variety of purposes, from the property it possesses of forming black compounds with vegetable astringent substances, such as gallic acid and tannin; and, as already stated, many of the vegetable dyes contain astringent matters. Iron is consequently of universal use, both as a mordant or base, and as an alterant, and from its sombre effect when used as an alterant it has got the significant epithet of "saddening."

In this salt, as with alumina, although the oxide of iron has a powerful attraction for the vegetable matters, still the acid which is in union with the oxide exercises a strong resistance. Thus, copperas having an excess of acid will not give so deep a dye upon cotton with the same quantity of sumach as dry neutral copperas, nor will either give so deep a tint as the same quantity of ferrous oxide if held in solution by acetic acid. Hence acetate of iron is a more powerful mordant than copperas. Moreover, the reaction of acetic acid upon the other colouring matters that are often present in the vegetable dyes renders that salt of iron much more useful than copperas for many purposes. The latter, however, is most generally used in the dye house. It is much cheaper, and can be applied with greater facility. Solutions of copperas are liable to become slightly changed by attracting oxygen, and the metal being converted into the sesqui. Iron does not in that state suit well for dyeing with astringent matters, as the ferric oxide (Fe_2O_3) reacts upon the vegetable dye, and causes loss.

Upon this reaction, and the effect of iron salts upon tannin and gallic acid generally, CRACE CALVERT made some interesting investigations. The conclusions at which he arrived were these:—1. There can be no doubt that tannic acid is the matter in tanning substances which produces black with iron mordants. 2. That the reason why gallic acid produces no black dye is to be found in the circumstance that it reduces the ferric oxide of iron in the mordant, forming a colourless and soluble gallate of protoxide of iron. 3. That gallic acid has the property of dissolving iron, and thus lays claim to the character of a true acid, whilst tannin, not having this action, appears to be in reality a neutral substance. These observations, some of which had been previously pointed out by NAPIER, must be of considerable importance to the dyer, and they agree with experience.

Copperas is also used as a mordant for dyeing blue by ferricyanide of potassium. Thus, 10 lbs. of cotton may be dyed a good rich blue by working it for fifteen minutes in a solution of 4 lbs. of copperas, wringing from this, and then working through a solution of 4 ozs. of the ferricyanide; finally, washing in cold water containing an ounce of alum in solution.

Copperas is also used as a dye by the oxidation of the iron within the fibre, thus:—

Iron Buff or Nankeen.—Take 2 lbs. of sulphate of iron and dissolve them in warm water, and then add the requisite quantity of water for working the goods; work in this for twenty minutes, and wring out, and put them immediately into a separate vessel filled with lime water, and work in this for fifteen minutes; wring out, and expose to the air for half an hour, when the goods will assume a buff colour. If the colour is not sufficiently deep, this operation may be repeated, working through the same copperas solution, but using fresh lime water each time. The goods are then washed through clean warm water, and dried.

Chloride of Iron is another salt seen in the dye house, and is prepared for use thus:—To 4 parts of hydrochloric acid add 2 parts of water, and apply a gentle heat, then add iron in pieces or filings, so long as it continues to be dissolved; then pour off the clear liquid into a basin, and evaporate, when greenish-coloured crystals of chloride will be obtained; but this salt crystallizes with difficulty, and deliquesces in the air, and should not be exposed. Instead of evaporating and crystallizing, the solution may be put into a bottle and reserved for use.

This salt is used for dyeing silks and woollens of a deep blue, and is preferred for that purpose to copperas.

To dye 5 lbs. of silk a rich deep blue, add to water required to work the silk 2 pints of chloride of iron, and 1 pint "double muriate" or chloride of tin; work in this half an hour; lift, and work in a solution of 8 ozs. ferrocyanide. If the colour be now the required depth, wash out in water in which 2 ozs. of alum have been dissolved; but if not sufficiently deep, put it again through the iron and ferricyanide solutions, and then wash out. The preparation of nitrate of iron, so as to suit various purposes, is fully described further on.

Prussian blues, and especially the variety known as royal blues upon woollens, are dyed upon a different principle from that followed in the case of cotton. Alternately working the goods in solutions of iron and of prussiate of potash leads to no satisfactory results. It is therefore necessary to work the wool in a solution of prussiate red or yellow, to which an acid mixture has been added. This decomposes the prussiate, and causes Prussian blue to be deposited upon the fibre. As a specimen of this method we give the following receipt, suitable for producing a fast blue upon 100 lbs. of wool or flannel:—Dissolve 8 lbs. red prussiate, 2 lbs. tartaric acid, 2 lbs. oxalic acid, and the following spirit in water at 208° Fahr., and in it work the goods well for ninety minutes. Lift, drain, rinse, and dry.

For the spirit take 1 lb. of granulated tin, 10 lbs. nitric acid at 36° B., the same weight muriatic acid at 22° F., and 10 lbs. sulphuric acid at 66° B., previously diluted with an equal weight of water.

This is a German process. In England the prussiate is generally decomposed by means of a mixture known as "royal blue spirits." In case of yellow prussiate, the acid mixture used may be sulphuric acid at 90° Tw. 1 gallon, muriatic acid at 32° Tw. half a gallon, and double aquafortis at 64° Tw. 1 quart. These ingredients should be put together in the open air, and no large stock should be mixed at once. When the red prussiate is intended to be used the nitric acid is quite needless.

The goods are finally bloomed by the addition of some "royal blue finishing spirits," for which purpose an oxalate of tin (see below) is employed.

It must be remembered that, both for silks and woollens, the Prussian blues of every shade are being more and more superseded by aniline blues, and that they will soon have a merely historical interest.

For Sky Blue.—The cotton should be previously bleached, then to a tub of cold water, sufficient to work the goods in easily, add half a pint nitrate of iron, and then work in this for twenty minutes; wring out, and pass through one tub of clean water. Into another tub of cold water add 4 ozs. ferrocyanide of potassium in solution, and about a wine-glassful of sulphuric acid; work the goods in this for fifteen minutes; wring out, and wash through cold water in which is dissolved 1 oz. of alum; wring out and dry.

To dye lighter or darker shades of sky-blue use less or more of the iron and ferrocyanide; or should the shade be too light after passing through the processes described, by repeating the operations through the same tubs, only adding an ounce more ferrocyanide, the shade will be deepened nearly double.

Napoleon Blue.—The cotton to be bleached before dyeing. Into a tub of cold water add 1 imperial pint of nitrate of iron and 2 gills hydrochloric acid, then add 3 ozs. crystals of tin, or a pint of "double muriate;" stir well, and immediately enter the goods, and work for thirty minutes; wring out, and put directly into the "prussiate tub," made up with water, into which is put a solution of 12 ozs. ferrocyanide and 1 wine-glassful of hydrochloric acid; work in this for fifteen minutes, then wash out in clean water in which is dissolved 2 ozs. alum. If a deeper shade of blue is required than these quantities will give, the goods are washed from the prussiate tub, without alum, in water, and passed again through the iron and ferrocyanide, and then washed out, as above, with alum in last water.

Royal Blue.—This is dyed in the same manner as the above; but the liquors are stronger—using 2 pints iron, 2 gills hydrochloric acid, and 4 ozs. tin crystals. The prussiate tub is made up by dissolving in it 1 lb. ferrocyanide of potassium, and adding 1 wine-glassful of sulphuric acid and 1 glassful hydrochloric acid. All the other operations are the same as the preceding. If not sufficiently dark with putting once through, repeat.

For 5 lbs. of silk the following proportions of stuffs are used:—

Sky Blue.—To a sufficient quantity of cold water to work the goods add half a pint of nitrate of iron; work in this for twenty minutes, then wash out in cold water.

Into another vessel of cold water add 3 ozs. ferrocyanide of potassium in solution, and 1 oz. by measure of strong sulphuric acid; work through this for ten minutes, then wash in cold water, in which an oz. of alum has been dissolved, and finish.

Royal Blue.—Into a vessel with cold water add 2 pints of nitrate of iron; then take 1 pint water and half a pint hydrochloric acid, and to this add 3 ozs. crystals of tin; when dissolved, add this to the vessel containing the iron, or 1 pint double muriate of tin; stir well, and enter the goods immediately, and work for half an hour.

Into another tub dissolve 8 ozs. of the ferrocyanide, and add to it 2 ozs. by measure of sulphuric acid; the goods are wrung out of the iron solution, and put directly into the second vessel with the ferrocyanide, working for fifteen minutes; then wash out in cold water, having 2 ozs. of alum dissolved in it, and finish.

Should the shade not be sufficiently deep, instead of washing in the alum water, they may be put back into the iron solution, and again through the ferrocyanide in the same way, and work the same time as first, only adding 2 ozs. of the latter salt before entering the second time into that vessel; then finish as stated.

Deeper shades are obtained by using more iron and tin, or by giving several dips.

Some wash out the iron solution before going into the ferrocyanide in one water, and also wash it out before putting back into the iron; the shade by this will not be so deep with the same stuff, but there is less risk of an unequal colour.

The finest royal blue on wool and worsted is dyed thus:—for 36 lbs. of goods take 4 lbs. yellow prussiate of potash and 6 lbs. of oxalic acid. Dissolve, and enter the goods at 100° Fahr., and work two hours, raising the temperature gradually to 180° Fahr. Lift and cool. Cool the dye-liquor also with two pails of water; add 21 lbs. alum, and work for half an hour, add three-quarters pint yellow spirits, and work for another hour, raising the temperature gradually to 180° Fahr. again, at which heat work for an hour and a quarter longer.

Lift and add 1 or 2 pints nitrate of iron, according to shade; re-enter the goods, and give five or six turns. Take out, cool, and wash very well. If a very dark shade is required, add a little logwood liquor to the nitrate of iron.

This blue is almost equal in bloom and lustre to aniline blue, but, as will be seen, it is an expensive colour.

It is almost unnecessary to repeat that different quantities will give various depths of colour.

Nankeen or buff colours are dyed directly upon cotton by the nitrate of iron. To a tub of hot water add 1 pint of nitrate of iron, and work in this for half an hour 10 lbs. of cotton previously bleached; wash out in water, and dry. No process could be more simple and easy, and this produces a permanent dye.

These few receipts will show the importance of iron as a dyeing agent. Its further use in the dyeing of blacks, slates, &c., will be given at the close of this article.

Acetate of Lead.—See Acetates.

Basic salts of the acetate of lead are prepared for dyeing oranges, and several deep shades of yellow, by boiling a solution of acetate, either white or brown, and adding to it a quantity of litharge, which is taken up, forming salts having two, three, and sometimes six proportions of oxide of lead to one of acid. These are found to be more suitable than the simple acetate. The only use of these lead salts in the dye house is for dyeing yellows, greens, and oranges. They have therefore no application apart from bichromate of potash, which has been already given.

Manganese.—Many years ago the salts of this metal were introduced as a dyeing agent in the production of browns, depending entirely upon the formation of an oxide of the metal within the fibre of the stuff.

The salts of manganese belong to the protoxide; but when the acid which is in union with the oxide is removed the protoxide passes into the peroxide, which has a deep brown colour approaching to black. So that when cotton was steeped or worked for a time in a solution, say, of protosulphate of manganese, and then through a weak solution of an alkali, the acid and alkali combined and were dissolved, while the oxide was left on the cotton. Hence, by exposure to air, it absorbed more oxygen, and passed to a brown; or by passing the cotton through a little bleaching liquor the oxidation of the manganese was immediately effected, and thus brown and fawns of various shades and depths were dyed, according to the strength of the manganese salt, or the number of times the operation was repeated. The colours produced by this means had a heavy dull appearance, and are now very seldom dyed, having been superseded by catechu, which produces similar colours of a lively rich hue.

Prussian Blue.—For the manufacture of red and yellow prussiate see article Potassium Salts. Here the use of these salts in the dye house for the production of Prussian blue will be dwelt upon. The salts of iron have a kind of reciprocal action upon these two salts of potassium, so that with the sesquioxide and yellow prussiate there is produced the same deep blue colour as with the protosalts of iron and red prussiate. This kind of action occurs with several metals, and gives the dyer a considerable power of varying his processes and tints. The following table exhibits these reactions:—

	Red Prussiate.	Yellow Prussiate.
Protosalts of manganese,	Brown, ...	White, becoming red.
Lead..................	No precipitate,	White.
Ferric salts, ...	No precipitate,	Deep blue,
Ferrous salts,..........	Deep blue,....	Bluish-white.
Copper, ...	Yellow-green,	Brown.
Stannous salts,.......	White,........	White.
Stannic salts,........		
Persalts of tin, ...	No precipitate,	Yellow.
Zinc,.................	Orange-yellow,	White.
Bismuth,..............	Yellow,.......	White.
Cadmium, ...	Yellow,.......	White.
Cobalt,................	Red-brown,....	Green.
Nickel, ...	Yellow-green, .	Greenish-white.

These two salts—yellow and red prussiate, *i.e.*, ferro- and ferri-cyanide of potassium—are of the utmost value to the dyer. From the above table it will be seen that different colours may be produced by using different metallic salts; as, for example, copper and ferrocyanide of potassium. By working the goods in a solution of sulphate of copper, and then passing them through a yellow solution of yellow prussiate, a rich brown is produced of great permanency, and this method is occasionally practised.

The principal use of these prussiate salts, however, is in dyeing blues by the salts of iron, examples of which have been given just above; other instances will also be appended, but in order to explain the nature of the process by which the colour is produced, the yellow prussiate may be defined as a double salt of iron and potassium, combined with cyanogen, namely, one part cyanide of iron and two parts cyanide of potassium.

The mere introduction of oxide of iron into a solution of yellow prussiate will not convert the iron into Prussian blue; and therefore, if a piece of calico, having its fibres saturated with oxide of iron, were passed through a solution of pure ferrocyanide of potassium, there would be no blue dye obtained, as the potassium would retain the cyanogen, and prevent it combining with the iron. The presence of an acid is requisite to unite with the alkali metal, thus setting the cyanogen free. When the goods are dyed by lifting them out of the iron solution, and putting them directly into the solution of yellow prussiate, in that case the acid of the iron seizes the potassium, and a mutual transference ensues.

When the cloth is charged with the iron salt, and the acid is removed either by washing or passing through an alkali, as is often done, in that case acid must be added to the prussiate solution to liberate the cyanogen. If care is not taken in practising this process, a certain loss will occur. When the acid is added to the prussiate solution, a great quantity of the cyanogen passes off as hydrocyanic acid, and forms a new compound of iron and the liberated cyanogen. This, indeed, is also a species of Prussian blue, but the product is far short in colour of what would be obtained if no acid had been added. These observations will guide the intelligent dyer in his mode of proceeding with this agent. The same remarks apply also to red prussiate in its practical application. Colours dyed by the prussiate should be dried by the air alone; for heat and moisture have a strong action on Prussian blue, producing first a reddish tint, which passes into lavender and then into grey, and if the action is continued, the tint is completely destroyed. It is easily affected also by the sun's rays, and likewise by washing in distilled or rain water. All alkaline matters destroy it. In the deeper shades of Prussian blue, where tin salts are used along with the iron, the colour is much more permanent. All kinds of fabrics —cotton, silk, and woollen—admit of being dyed Prussian blue.

TARTAR.—*Argol—Cream of Tartar—Bitartrate of Potash.*—This salt is much used as an adjunct in the dyeing of woollen stuffs. It is seldom employed alone, but mostly with alum, sulphate of iron, and chloride of tin. Its use, along with these bodies, is very important, owing, as is generally supposed, to a decomposition taking place, in which the sulphuric acid of the alum and iron, and the chlorine of the tin, unite with the potash of the tartar, resulting in the formation of a tartrate of alumina, iron, or tin, which combines more easily with the woollen stuff. With reference to this action DUMAS has the following:—

"Cream of tartar, or bitartrate of potash, constitutes by itself a very feeble mordant, but which is often used in dyeing light woollen stuffs, to which one may wish to give a delicate but brilliant shade. It is also employed in the dyeing of ordinary woollen goods, but here it is associated with alum, sulphate of iron, chloride of tin, &c. Its influence under these circumstances consists evidently in determining a double decomposition, from which a sulphate of potash or chloride of potassium is produced, whilst the tartaric acid combines with the alumina, the sesquioxide of iron, or the oxide of tin. Now, it is very probable that the colouring matters remove the alumina, the sesquioxide of iron, or the oxide of tin, more readily from tartaric than from sulphuric acid. Moreover, the presence of free sulphuric acid would certainly prove injurious, as well to the stuff as to the colouring matter, whilst free tartaric acid can exercise no unfavourable action over them."

The operation of subjecting wool to the alum mordant is always effected at the boiling point; the mixture used in this process is a compound of alum and of cream of tartar. One of the objects of this addition is to free the bath of the carbonate of lime which the water generally retains in solution, and which, acting on the alum, would determine its partial decomposition by producing an insoluble aluminous sulphate of aluminium and potassium, and this accumulating on the stuff, and becoming unequally fixed upon its surface, would lead to stains or blotches on passing the material through the dye bath. But, independently of the above effect, which might be produced by any acid, cream of tartar appears to be capable of effecting a further object, by inducing a double decomposition, which transforms the alum into a tartrate of aluminium. However this may be, after one or two hours boiling in the alum bath, the cloth, which should be constantly agitated so as to cause a more equal application of the mordant, is withdrawn from the copper, and after thoroughly draining, it should be put aside for two or three days, when it is wished to dye it with any full-bodied colour. Experience has proved that this repose after the use of the mordant greatly favours the union of the latter with the stuff. In applying the tin mordants, use is also made of cream of tartar. It is, moreover, an indispensable addition where it is desired to fix the salts of iron previously to dyeing in black.

Woollen cloth on being dipped into a cold aqueous solution of alum appropriates to itself a part of this salt, but without undergoing any very sensible alteration. MM. THÉNARD and ROARD have, indeed, proved that cloth, when thus treated by a cold solution of alum, gives up this salt to boiling water, and that after a few washings performed at the boiling point it will have parted with the whole of the alum which it had received in the cold bath. When, however, cloth is boiled in a solution of alum, it yields to this liquid a portion of its organic matter, which becomes dissolved; but, at the same time, it absorbs an equal amount of the alum.

It will now merely be necessary to show the action which wool undergoes when brought into contact with alum and cream of tartar at one and the same time. It is very possible that there may be in this case a simultaneous fixing of alum, as well as of the double tartrate of aluminium and potassium, and of tartaric acid. The presence of alum in the cloth when taken from the boiling solution is very evident; that of tartrate of aluminium and potassium and of free tartaric acid is only presumable.

Tartar is often adulterated when sold to the dyer. Its adulterations are generally sand, carbonate of lime, alum, and sulphate of potassium. By boiling 100 grains of the tartar in a solution of carbonate of potash or borax, the sand, if any be present, will remain as an insoluble residue, and may be weighed.

Take another 100 grains of the same, finely ground, to which add a little water, and then a little dilute hydrochloric acid; if chalk be present, there will be effervescence. After allowing it to stand for half an hour, add ammonia till the solution smells of that alkali; then put the whole upon a filter, and wash. To the clear filtrate add a solution of ammonium oxalate, which will precipitate the lime; this, when filtered and burned, gives the quantity of carbonate of lime in the sample.

Dissolve another portion in water, with a little hydrochloric acid, and filter; to a part of the filtrate add a few drops of chloride of barium; if a white precipitate is formed, sulphuric acid is present. To the other portion of the filtrate add ammonia; if no precipitate is formed by this, then the adulterant will be sulphate or bisulphate of potassium; but should there be a white gelatinous precipitate by ammonia, alum is present in the tartar. The latter salt is not injurious to the process to which the tartar is applied by the dyer; but it is well that he should know the quality of the stuff before using it.

Tin.—The oxides of this metal have been long known as a mordant for dyeing, as stated in the course of the historical remarks; and the salts of tin are still among the most useful and extensively used of any substances in the art. The oxides have a strong affinity for vegetable colouring matters, and also a strong tendency to combine with or become insoluble within the fibres of the goods submitted to their action, thus rendering them peculiarly suitable as mordants. Tin combines with oxygen in different proportions, while its oxides combine with acids, and give rise to a series of salts of distinctive qualities, but all more or less useful in dyeing. These oxides have the following composition:—

Monoxide or stannous oxide,	SnO
Sesquioxide,	Sn_2O_3
Dioxide or stannic oxide,	SnO_2

The first and last of these form with acids permanent salts, which are distinguished as stannous and stannic salts. The sesquioxide salts are used in dyeing under the name of "bowl spirits" or "nitrate of tin."

Hydrated stannous chloride, tin salt, $SnCl_2,2H_2O$, is obtained in the market in the form of white prismatic crystals, which, according to Penny, contain two equivalents of water, and are therefore composed of—

Tin,	52
Chlorine,	32
Water,	16
	100

Other chemists, however, have assigned three atoms of water, in which case the composition will be—

Tin,	48·1
Chlorine,	29·5
Water,	22·4
	100·0

The quantity of tin found in the salts of commerce generally agrees better with the latter analysis than the former. When these salts are put into water they produce a milky-coloured solution, owing to the formation of an oxychloride of tin, which is insoluble. A little hydrochloric acid put into the water prevents this to a large extent.

Besides these crystals of tin, there are also obtained in the market solutions of dichloride of tin, under the name of "single" and "double muriate." The former is a solution of tin in hydrochloric acid, with excess of acid, and the whole diluted with water. The quantity of tin in good single muriate is 12 per cent.—$SnCl_2$ (stannous chloride).

Double muriate is a strong solution of the protochloride, $SnCl_2$; it contains about 25 per cent. of tin. Both these salts vary very much in quality, and should always be subjected to a testing process. That recommended by Penny is very easy and simple, and also very correct in its results.

Dichloride of tin is extensively employed by dyers and printers under the names of crystals, or salt of tin, and single and double muriate of tin; the first is the salt in its crystallized state, and the others are solutions of it in water, with excess of hydrochloric acid. The consumption of these articles is very considerable. In Glasgow alone the production of crystals of tin, in the course of a year, is estimated at from 150 to 200 tons; and in Manchester and its neighbourhood the annual consumption is even greater than this, being perhaps not less than from 250 to 300 tons.

The principal adventitious matters contained in the crystallized chloride are water and excess of hydrochloric acid, arising from imperfect drainage of the crystals. This is particularly the case with fibrous or feathery crystals, which have the power of retaining mechanically a considerable proportion of the mother liquor.

The value of tin salts, as respects the several purposes to which they are applied in dyeing, depends evidently on the amount of tin they contain; it being also essential that the metal should exist exclusively in the state of stannous chloride.

The agent which Penny was the first to propose to employ is bichromate of potash. Its application is based upon the fact that chromic acid, in presence of free hydrochloric acid, converts dichloride of tin into tetrachloride, the chromic acid becoming sesquichloride of chromium. The details of the process will be found below.

Sesquichloride of tin (stannous-stannic chloride, Sn_4Cl_6) may be prepared by putting into a solution of dichloride of tin a quantity of newly precipitated sesquioxide of iron, when a double decomposition takes place. Two parts of dichloride of tin and 1 part of the sesquioxide give 2 of monochloride of iron and 1 of sesquioxide of tin.

This sesquioxide of tin is precipitated, collected, washed free of iron, and then redissolved in hydrochloric acid, forming a stannous-stannic compound of chlorine. This salt has several distinctive properties in its reaction with other bodies; and in many practical operations in dyeing it is more than probable that this class of salts plays an important part. It will be seen, under the head Iron in this article, that some of the blues there mentioned are, in all probability, dependent upon the formation of this salt for their peculiar tint.

Stannic salts are produced by the solution of the dioxide in an acid. The principal acid salt of this sort used in the dye-house is the dichloride. When tin is dissolved in hydrochloric acid, with nitric acid present, and the temperature is allowed to rise, a tetrachloride will be formed. Dyers, in dissolving for mordants, generally use a mixture of hydrochloric and nitric acids. If care be taken to keep the solution cool a dichloride is formed, notwithstanding the presence of nitric acid; but should tin be added in too great quantity at a time, the heat will be so much increased by the rapid action that a tetrachloride will be the result; and there is often produced, in the preparation of these salts, a mixture of monosalts, sesquisalts, and disalts. Hence the cause of the irregularity of tint produced by tin mordants thus prepared; very great care must therefore be taken in the preparation of such salts.

Tetrachloride, $SnCl_4$, is often desirable as a mordant, and in that case it may be prepared by dissolving some crystals of the salts of tin, or a quantity of single or double muriate, and passing through the solution a current of chlorine gas (see Chlorine), or by heating the solution, and adding to it when hot some nitric acid. Care must be taken in this last process not to add the acid in too great quantity at a time, as violent effervescence ensues, and the contents will boil over, causing loss. The technical name of the tetrachloride of tin or stannic chloride is "oxychloride."

The acid preparations of tin used in dyeing are called "spirits," with a term prefixed to each, denoting their particular application, as red spirits, barwood spirits, plum spirits, &c. Their preparation is performed by melting the tin in an iron pot and pouring the metal from some height into a vessel filled with cold water, which granulates the tin into lamellar masses. This process is termed "feathering" the tin.

Acetates and *oxalates of tin* are also used occasionally for dyeing purposes by adding a solution of acetate of sodium or potassium to chloride of tin for the acetate, and a solution of oxalate of soda or potassa for the oxalate of tin. In both cases a double decomposition takes place, the chlorine combining with the alkali and the acid with the tin. The reactions and the precipitates of the acid salts of tin, with other reagents, are as follow:—

	Monosalts.	Disalts.
Potash and soda,	White, soluble in excess,	White, soluble in excess.
Ammonia,	White, insoluble in excess,	White, soluble in excess.
Carbonate of the alkalies,	White, soluble in caustic alkalies,	White, soluble in caustic alkalies.
Yellow prussiate,	White,	None.
Red prussiate,	White,	None.
Galls,	Slight yellow,	None.
Gold,	Deep purple,	None.
Sulphides of the alkalies,	Brown,	Yellow, soluble in caustic potassa.

Besides the acid salts of tin there is a series of alkaline salts, in which the stannic oxide combines with alkalies in the same manner as an acid, and forms definite compounds, named stannates. The stannate of soda has been of late years extensively used as a dyeing agent. The mode of its preparation has been the subject of several patents. The general method is to fuse the oxide of tin with soda, either caustic or carbonate, at a red heat, then dissolving the fused mass in water, and crystallizing. When metallic tin is used instead of oxide, a quantity of nitrate of potassa is put in with the alkali, which by decomposition converts the tin into an oxide. The following extracts from the specification of James Young's patent will give a general idea of the methods by which such salts are to be prepared, including stannates and stannites of the alkalies:—

Firstly. To make stannate of soda, he puts a quantity of tin ore, or what is commonly known in Cornwall by the name of *black tin*, reduced to powder, into an iron pot, along with a solution of caustic soda, and sets the pot on a fire to boil. The proportions in which he uses these ingredients vary with their respective qualities. If the ore contain 70 per cent. of tin, he employs about two and a half times its weight of caustic soda liquor, containing about 22 per cent. of soda, increasing or diminishing the proportion of the liquor employed according as it is desired to produce a stannate with a greater or less excess of alkali. The materials are kept well stirred and the heat gradually raised up to between 500° and 600° Fahr., at which temperature the ore is acted upon by the soda, and the tin or oxide of tin contained therein, or the greater part thereof, combines with the alkali. The progress of the operation may be known from time to time by taking out of the pot a small portion of the mass, and ascertaining how much of it dissolves in water, and how much of the ore has been left unacted upon. The hot mass is then transferred from the pot to another vessel, and set to cool. And when cooled it is mixed with water, when any insoluble matters which may have remained in it, unaffected by the caustic soda, are easily separated by filtration or by subsidence. The clear liquor which remains is the stannate required, which may be either employed in that state or evaporated to dryness, or crystallized, the solid salt being dissolved as required for use.

Secondly. This chemist also prepares stannate of soda by mixing a quantity of tin ore, reduced to powder, with one and a half times its weight of nitrate of soda, subjecting the mixture to a red heat in an iron vessel, passing a current of steam over it, and keeping it constantly stirred during the operation, in order to expose fresh portions of it to the action of the steam. Nitric and nitrous acids are given off in fumes, which may be condensed with water, and collected as collateral products—reducing thereby the cost of the stannate. Stannate remains, which may be freed from its insoluble impurities by mixing it with water, and filtration or subsidence, as in the process first before described; and it may be also left either in a state of solution, or crystallized or evaporated, as aforesaid.

Thirdly. He substitutes for the nitrate of soda employed in the last preceding process chloride of sodium—common salt—using, however, equal weights of the salt and tin ore; and pursuing the same method in all other respects, he also obtains thereby stannate of soda, with hydrochloric acid as the collateral product.

Fourthly. He procures by the following process both stannite of soda and stannate of soda. He subjects to a red heat a quantity of metallic tin, mixed with an equal weight of solid hydrate of caustic soda (which may be obtained by boiling down caustic soda liquor, say 3½ cwts. of the liquor containing 22 per cent. of soda to about 1 cwt. of the hydrate), stirring the materials well during the operation; whereupon the water of the sodium hydrate becomes decomposed, and parts with its oxygen to the tin, and the stannous oxide so formed, uniting with the soda, forms a stannite of soda, suitable for some dyeing and printing purposes. To convert this stannite of soda into a stannate of soda, it is boiled in water, on which a portion of metallic tin is precipitated in the form of a black powder, and the solution remaining is stannate of soda. Or, 20 parts of metallic tin are taken, 16 parts of solid hydrate of caustic soda, and 3 parts of oxide of manganese, all by weight, and subjected to a red heat in an open pot, keeping the mixture constantly agitated, and allowing a free access of air. So small a portion of oxide of manganese as is contained in this mixture would be quite insufficient of itself to further oxidize all the tin, but this oxide of manganese is converted by the heat and absorption of oxygen from the atmosphere into a manganate of sodium, which salt becomes decomposed by the tin, and part of it goes to form dioxide of tin, leaving a residuum of oxide of manganese; this becomes once more, by a new absorption of atmospheric oxygen, a manganate, which is decomposed by the tin as before, yielding a fresh accession of binoxide of tin; and so the process goes on until all, or nearly all, the tin has become stannic acid and combined with the soda. The mass in the pot is then dissolved in water, and the solution clarified by filtration or subsidence. The supernatant liquid is a solution of stannate of soda, which may be either left as it is, or crystallized, or evaporated to dryness, as aforesaid. The precipitated oxide of manganese may be collected and used over again for the same purpose.

The stannite formed in the first of the processes described under this branch of YOUNG's specification, may be changed into stannate of soda by merely keeping it freely exposed at a red heat to the atmosphere for a sufficient length of time; but preference is given to manganese as the oxidizing agent, being more expeditious, and, on the whole, cheaper.

Fifthly. He also employs for the formation of stannate of soda, oxide of tin, which is obtained by heating metallic tin to redness in an iron vessel, keeping it well stirred, and passing a current of steam or air over it. And this oxide of tin is treated, along with caustic soda, in precisely the same way as the ore has been before directed to be managed.

Sixthly. Stannate of potash is manufactured by each and every of the methods before described of manufacturing stannate of soda, substituting only in each case where caustic soda, or nitrate of soda, or chloride of sodium is directed to be employed, an equivalent of caustic potash, or of nitrate of potash, or of the chloride of potassium, as the case may be.

Seventhly. This chemist also manufactures stannite of potash by the same process as stannite of soda is before directed to be produced, substituting for the hydrate of soda an equivalent of hydrate of potash.

Another preparation of tin with alkalies has been introduced into dyeing operations—a double salt of soda with arsenic and stannic acids, termed arseno-stannate or arseno-stannite of soda. Unless applied to some purpose for which no substitute could be used with anything like the same advantage, the use of these deadly poisons should be avoided. At all events, a higher motive should exist than mere economy in producing a certain tint upon a dyed or printed article.

Stannate of soda is used as a mordant in print and dye works. Numerous experiments have been made with it on a large scale, to decide whether, in calico printing or dyeing, the hydrated dioxide of tin alone would be preferable to an arseniate of the same oxide as a mordant. The result of comparative trials leads to the preference of hydrated stannic oxide alone, the various shades being more brilliant and less liable to unevenness than when arsenic acid is present. It would be desirable to substitute in commerce a purer stannate of soda for that at present sold, as well as for that containing arseniate of soda.

ZINC.—The only salt of this metal used in the dye house is the sulphate—white copperas or white vitriol—and even this is not used to any great extent, nor for the direct purpose of a dye or mordant, but for certain qualities which the oxide possesses in reacting upon other mordants; and as the precipitate with zinc salts are mostly all white, the sulphate is occasionally used to modify the action of stronger agents, by a double decomposition, where the oxide formed does not affect the tint, as in bichromate of potash in dyeing yellows. Further, as it parts with a portion of its oxygen when in contact with deoxidizing agents, it is made to serve a purpose in some of the processes in calico printing.

ORGANIC COLOURING MATTERS.—The majority of these are sufficiently described in the introduction to this article; it is only needful here to give a few manipulative details respecting the most important of them.

ARCHIL *or Orchil.—Orseille*, French; *Persio*, German. —A violet-coloured paste prepared from different species of lichens, particularly *Roccella tinctoria*, *R. corallina*.

Orchil may be regarded as the English, *cudbear* as the Scotch, and *litmus* as the Dutch name for one and the same substance; the first being generally fabricated in the form of a liquid of a beautiful reddish or purple hue, the second chiefly in that of a powder of a lake or red colour, while the third is in that of small blue parallelopipeds or cakes. The latter variety differs in the greatest degree from the others in colour and consistence; its tinge is imparted by the addition of an alkaline carbonate, and sometimes, as an adulteration, of indigo; and its consistence by the presence of thickening agents, such as gypsum, starch, chalk, or various silicious and argillaceous matters.

Archil, cudbear, and litmus are now manufactured in England, either from the same species of dye-lichen, or from a variety of kinds, by altering the process of manufacture.

The lichens, which are principally collected on rocks adjacent to the sea, are cleaned and ground into a pulp with water; ammoniacal liquors are from time to time added, and the mass is frequently agitated, to expose it as much as possible to the action of the atmosphere. The colouring matter is thus expressed. Chalk, plaster of Paris, or other substance, is sometimes added to it to increase its consistency.

In the most recent process the lichens, previously sorted and washed several times with cold water, are ground up to a somewhat liquid paste. This paste is exhausted by washing several times with cold water. The liquids obtained are filtered through a peculiar kind of loosely-woven, felty, woollen tissue, which retains the ligneous matter, but admits of the passage of the partly dissolved, partly suspended colorable acids. By the addition of a small quantity of bichloride of tin the colouring matters are coagulated and collected on filters made of stout linen tissue After having been once more washed with water the mass is dissolved in ammonia, and placed in properly-constructed tanks, wherein, by the aid of a suitable temperature and frequent stirring, the material is converted into orchil. The operation is one which occupies a long time. Its progress is tested by dyeing, with a certain weight of the orchil, a certain size of woollen tissue.

Archil Paste.—The ordinary method of preparing archil paste is as follows:—The apparatus used is a wrought-iron horizontal cylinder, made very smooth within, about 6 feet in length and 3 feet in diameter. The lowest third part of the circumference for the entire length is fitted with a steam jacket for the application of heat. A shaft runs through the cylinder axially from end to end, with a movable lid for introducing the charge of weed and ammonia. There are also a few small slides for regulating the supply of air.

A cylinder of the dimensions given is charged with 100 lbs. of weed and 540 lbs. of ammonia at 5° of the common ammonia glass, which corresponds almost exactly with Beaumé's hydrometer for liquids lighter than water. The charge can be ready in three days, but the quality is improved if worked for a week. Steam is admitted into the casing by a pipe at the end opposite the man-hole, and the temperature is kept up to such a height that the paste feels slightly uncomfortable to the hand—about 140° Fahr. (60° C.). The agitator is kept gently revolving during the whole time.

The yield for the quantity above given is 540 lbs., or three times the weight of the weed employed.

An excess of ammonia renders the colour less stable, impairing its affinity for the fibre. It should be mentioned that the blue shade makes its appearance first, and by proper management the change can, if desired, be arrested at this point. The red shade appears when the joint action of air and ammonia is allowed to proceed to a greater length.

Archil Liquor.—The weeds are boiled out with water and strained; the extract is concentrated to 8° to 10° Tw., and then reheated and agitated with ammonia at 24° of the ammonia glass. Continual agitation is here not necessary.

The arrangements for extracting the weeds are various. It is generally boiled in three successive waters, the first and second liquors being mixed and concentrated, whilst the third serves for the first extraction of a fresh quantity of the woad.

The weeds for paste and liquor should not be ground too fine, put should be bruised under edge-stones rather than pulverized. Certain additions are frequently made by manufacturers.

Small quantities of red prussiate (potassium ferricyanide) gives the archil a redder tone, whilst a slight addition of a fixed alkali (generally carbonate of potash) gives an extra blue shade. A little tartar or white argol improves the bloom and brilliancy.

Cudbear.—Archil paste, made as above described, is dried at a steam-heat, and afterwards ground to a fine powder in a lac-mill. It is very generally weighted with common salt, and its appearance is often factitiously improved by the addition of a little magenta.

Archil is sometimes fraudulently mixed with extracts of logwood, sapan, &c.

When the amount of logwood extract in archil is considerable, it will be indicated, on the addition of alum or protochloride of tin, by the shade produced, as compared with pure orchil treated in the same manner. These reactions, however, are not decisive, and are of value only when taken together with others.

When about 50 drops of pure archil, diluted with 3 ozs. of water, and slightly acidified by means of acetic acid, are mixed with 50 drops of fresh solution of protochloride of tin—1 part of the salt in 2 of water—and heated in a flask upon a sand-bath, the colour is almost entirely destroyed when the liquid is at the boiling point, presenting only a yellowish tinge.

A drop of logwood extract, diluted with 3 ozs. of water, and treated in the same manner, produces a distinct violet, which remains unaltered after several hours' boiling.

The violet colour produced by logwood extract is capable of indicating the presence of logwood, even when it does not amount to more than 3 or 4 per cent. of the orchil. The boiled liquid has then a permanent grey tint.

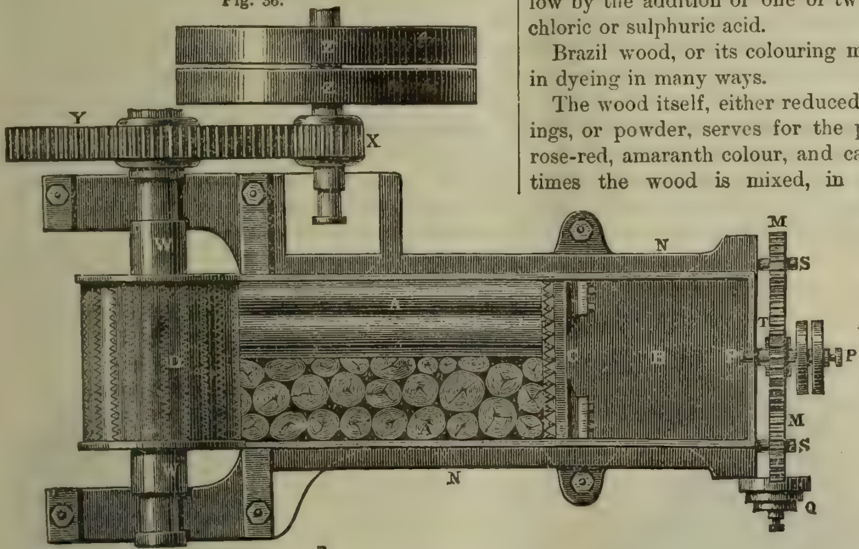
When the adulterating substance is extract of lima or sapan wood, the boiled liquid retains a red hue.

Blue archil, when mixed with a small quantity of ferrocyanide of potassium, acquires all the properties of the red. The presence of the ferrocyanide does not interfere with the above method of testing for wood extracts.

Archil and cudbear are extensively used in dyeing woollen for a great many colours, as purple, lavender, lilacs, also in browns, chocolate, &c. It is also used for silk, for several tints of lavender, violets, and as a ground for crimsons, &c.; but it is not used for cotton, having no affinity for that fibre.

BRAZIL WOOD.—*Bois de Pernambouc*, French; *Brazilienholz*, German.—There are several varieties of this wood, distinguished from one another by the name of the locality where they are obtained, as Pernambuco, Santa Marta, Sapan, &c. By the dyers they are often all named peachwood, from an inferior sort much in use, and procured from Campeachy.

Fig. 36.



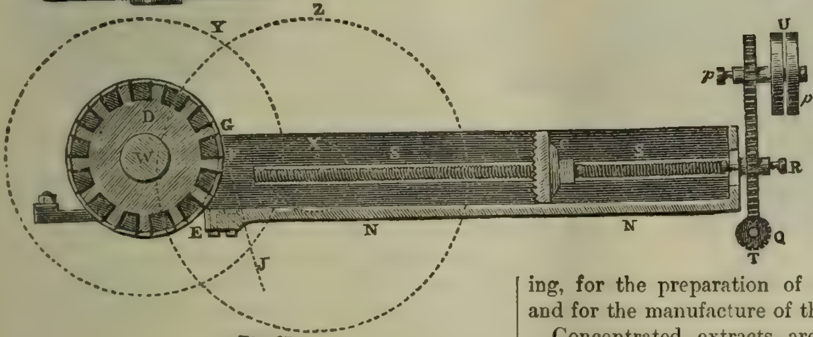


Fig. 37.

The Brazil wood tree, botanically termed *Cæsalpinia crista*, is a production of America. The Portuguese government early discovered its value, and made it a royal monopoly; hence was derived its obsolete and nearly forgotten name of *Queen-wood*. It mostly vegetates in dry places and amongst rocks; its trunk is large, crooked, and knotty.

The wood known in commerce as Pernambuco contains a larger amount of colouring matter than the others, and is most esteemed. It is hard, and is yellow when newly cut, but becomes red on exposure to the air. Lima wood is much the same in quality. Sapan wood grows in Japan, and stands next in value to the two before mentioned. It is not abundant, but is much prized for a certain shade of red, affording a clear, fine colour. Peach, or Nicaragua, sometimes called Santa Marta wood, is inferior in quality, but for some purposes is preferred, although the amount of colouring principle is not so great.

Brazil wood is distinguished from logwood by its paler colour, and by the precipitates which it gives with acetate of lead, protochloride of tin, and lime-water, which, instead of being violet as with logwood, are crimson. Both their infusions are rendered yellow by the addition of one or two drops of hydrochloric or sulphuric acid.

Brazil wood, or its colouring matter, is employed in dyeing in many ways.

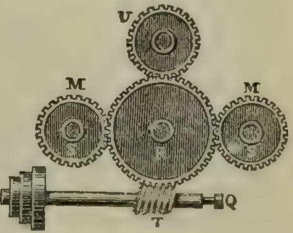
The wood itself, either reduced to shavings, raspings, or powder, serves for the production of red, rose-red, amaranth colour, and carmine red; sometimes the wood is mixed, in smaller or larger proportion, with garancin, for the dyeing of the so-called garancin colours. The wood is used in a mechanically divided state for the preparation of the decoction and concentrated extracts.

Decoction, or liquor of Brazil wood, is obtained by boiling, by means of steam, the raspings of the wood with from 18 to 20 times its weight of water, or by the exhaustion of the wood by displacement with boiling water. This liquor is used for dyeing, for the preparation of concentrated extracts, and for the manufacture of the Brazil lakes.

Concentrated extracts are now made having a specific gravity of 1·075, 1·162, or are even evaporated to solidity. The process used is much the same for all dyewoods.

Extracts of the Woods.—This manufacture is of comparatively recent date; it has sprung up with the more extensive use of the wood dyes, which in the raw state are not well fitted for calico printing.

Fig. 38.



By means of suitable machinery (of which the engine shown in Figs. 36, 37, 38 may be taken as a convenient form), the woods are reduced to a coarse powder, or to small chips, cut generally in a direction perpendicular to their fibres. This operation requires a large amount of motive power.

The machine to be described was designed by WILLMER, and is extensively used on the Continent. It is shown in plan in Fig. 36, and in longitudinal section in Fig. 37. Fig. 38 displays the mechanism by which the wood is pushed forward to the cutting or rasping wheel. (The same letters apply to each engraving.) The driving wheels, Z Z, are put in motion by a band from a steam engine or water wheel; they work the cog wheels, X and Y, and thus cause the axle, W, to revolve, which latter carries upon it the rasping or cutting cylinder, D. An iron bed, N B, serves for the reception of the wood to be rasped.

The wood is conveyed to the rasping cylinder by a constant pressure being exerted upon it by the plate, C, which is itself forced forward by the two screws, S S, parallel to the bed, N B N, upon which the plate, C, travels. (One of these screws is shown in Fig. 37.)

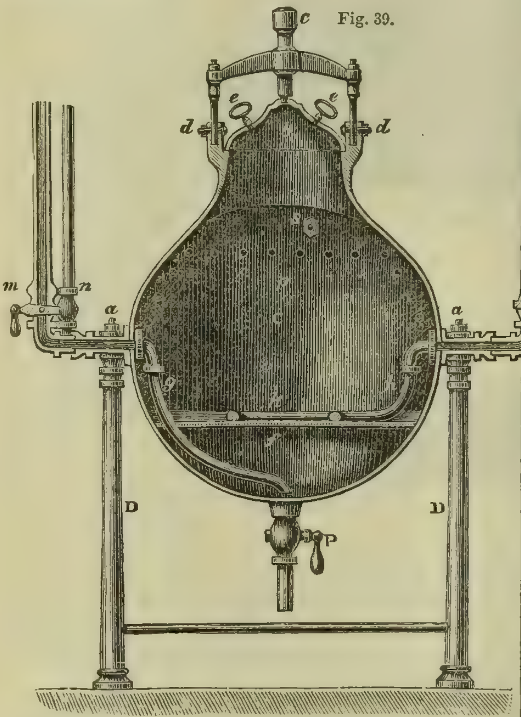


Fig. 39.

The movement of the screws, S S, is effected by the toothed wheels, M M (Fig. 38), upon the main wheel, R, which is itself moved by the endless screw, T, upon the axle, Q. When it becomes necessary to refill the bed with wood, the plate, C, is rapidly drawn backwards by the cog wheel above R, which is started and stopped when desired by the loose and fixed pulleys, U, upon the axle, P *p*.

In order to prevent the blocking up of the cutters of the wheel, D, by pieces of wood fixing themselves upon the spikes of the cylinder, Willmer recommends that the pressure plate, C, be set parallel with the tangent line, F J, Fig. 37.

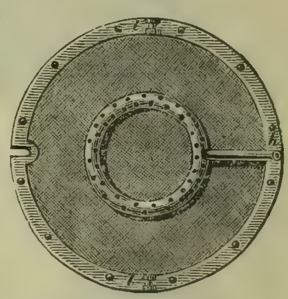
The wood will be ground much finer if a layer of long logs, A (Fig. 36), is disposed lengthwise on the top of the shorter pieces, as movement of the blocks under the rasp is thus rendered less easy.

The coarse powder or chips thus obtained are directly exhausted by means of water, or are left exposed in heaps, in a moist state, to a kind of oxidizing fermentation, whereby the solubility of the colouring matter is increased, and the subsequent exhaustion by water is rendered more easy.

It is important to carry on the exhaustion of the woods with the least possible expenditure of water, because the greater part of that vehicle has to be afterwards got rid of by evaporation. Some manufacturers carry on their operations in open tanks, applying water at 60° to 100° C.; but others prefer to work at a temperature above 100° C., and this has, of course, to be done in closed vessels.

The annexed sketches (Figs. 39 and 40) show the construction of steam-extraction vessels. The copper vessel, C, in which the extraction is effected, is pear-shaped, and rests upon two hollow wrought-iron axles, *a a*, supported between two cast-iron columns, DD, so that *c*, at the top of the figure, can, by turning the boiler round, be brought to where P stands in Fig. 39, and be reversed again if required. *b* is a manhole, hermetically closed by means of the screw, *c*, running through the frame, which is bolted to the neck of the pan at *d d*. In the interior of the pan is a false copper bottom, *f*, perforated with fine holes, and held in its place by screws at *i i*, fig. 40; above this is fastened a piece of brass wire-gauze of narrow gauge. On this rests the perforated worm tube, *k*, which by means of the pipe, *h l*, communicates with a steam-boiler. The pipe, *g*, which runs into the cavity, *f*, beneath the false bottom, is in connection with three tubes, *m*, *n*, and *o* (the latter is not, however, visible in the cut, being placed in front of and before *n*); *m* serves for the introduction of pure water. The pipes *n* and *o* convey the extracted dyestuff to barrels or vats by the steam pressure on the pan. The large tap, P, at the bottom of the pan, is for the removal of the dregs before the vessel is refilled with wood.

Fig. 40.



The mode of working is thus:—All the taps are closed, and the cap, *b*, lifted off by its handles, *e e*, and the finely-ground wood introduced. The tap, *p*, is opened, and water is then run into the pan through the tap, *m*, until it begins to flow out at the small tap, *p*; both taps are then closed, the cap, *b*, replaced, and secured by the screw, *c*. The steam tap, *l*, is next opened, and steam of the pressure of half an atmosphere allowed to enter and diffuse itself amongst the contents of the pan. In about half an hour the first extraction will be finished; during this time the level of the water must be kept between the two small taps, *p* and *s*.

On the conclusion of the operation the tap, *n*, is opened, and the dyestuff forced by the steam pressure through the pipe, *g*, into the pipe, *n*, and thence to the barrels or vats. Water is again let into the pan, and a second extract made, which is sent after the first. A third extract is also made, but being far inferior in quality it is not mixed with the first two, but is forced through the pipe, *o*, to be dealt with separately. The dregs of the dye liquor are then drawn off by opening the tap, P, and after draining the boiler, the cover *b*, is taken off, and the exhausted dyewood emptied out by turning the pan upside down.

The evaporation of the liquors obtained from the exhaustion of the dyewoods with water is effected in various ways; sometimes vacuum pans are used, but they do not answer the purpose well for extracts which have to be concentrated above the specific gravity 1·134, on account chiefly of the difficulty experienced by the bubbles of aqueous vapour in escaping from a mass of viscous liquid; the evaporation is therefore most frequently carried on in double bottomed shallow pans heated by steam.

CATECHU—*Cachou*, French; *Kaschu*, German; *Catechu*, Latin—is an extract of the Khair-tree (*Acacia catechu* or *Mimosa catechu*) of Bombay, Bengal, and other parts of India. It was long regarded as of earthy origin, and bore the name of *terra Japonica*, or Japan earth.

As soon as the trees are felled the whole of the exterior white wood is carefully removed, and the interior coloured portion cut into fragments, which are placed in narrow-mouthed unglazed pots, and water added in sufficient quantity to cover them. Heat is then applied and maintained till the decoction is half evaporated, when, without being strained, it is transferred to a shallow earthen vessel, and further reduced two-thirds by boiling. It is next left at rest in a cool situation for a day, and is afterwards evaporated by the heat of the sun, being occasionally stirred during that time.

The extract thus prepared yields three varieties of catechu, viz.:—

Pegu Catechu.—The cutch or leaves met with in the trade in cakes weighing from 35 to 45 kilos., packed in large leaves. It is a dry, glossy, brownish-red or blackish-brown substance, of uniform texture throughout, and of a specific gravity 1·39.

Brown Cutch.—This is a less pure article; it is cast in sand or clay moulds.

Brown Catechu.—This kind of cutch is imported from Java, Singapore, Pegu (viâ Calcutta). It is sold in cubic-shaped cakes, packed in coarse bags, weighing from 35 to 40 kilos. per cake.

Bengal Cutch is obtained by a similar process to that above described from the fruit of the areca palm (*Areca catechu*), a tree widely spread over the tropical portion of Asia. It is met with in commerce in cubical cakes, each side measuring from 3 to 4 centimètres. The colour of Bengal cutch is brighter than that of the cutch shipped at Bombay (the mixed produce of the *Acacia catechu* and areca nut), the colour being chocolate brown, with deep and light coloured bands. It exhibits a dull appearance when broken, and is very dry and sandy, although sand is not necessarily present. Its specific gravity is 1·28.

Yellow Cutch, *Cubical Cutch*, or *Gambir*, is the extract obtained from the leaves of the *Uncaria gambir* and *Uncaria acida*, shrubs belonging to the family of the *Rubiaceæ*, tribe of the cinchonas, abundantly met with in Sumatra, Malacca, Pulo-Penang, Singapore, and the Sunda Islands. This kind of cutch, known very generally as "gambir," occurs in commerce in the shape of flat cakes, externally brown, internally yellow, fracture dull, taste bitter and astringent.

Catechu is often adulterated with various other astringent principles, or by the incorporation of clay, sand, ochre, and similar bodies. When other extracts have been mixed with it, it has often a dark and almost black colour, with a shining appearance, and occasionally feels glutinous or clammy.

The reactions of catechu are so varied, that it is now used for most compound colours, as black, brown, green, drab, and fawn; and its permanency renders it of high value.

It was first used for dyeing brown upon cotton, which is dyed by a very simple process. A little catechu is dissolved in boiling water, and a small portion of nitrate or sulphate of copper added to it; the cotton is wrought or steeped in this for an hour or two, and then taken out and wrought through a hot solution of bichromate of potash, which produces a brown of very great richness: it is washed from this, and then passed through a little soap and water, which softens the fibre.

CHICA is a red colouring principle, used by some Indian tribes for staining the skin, and is extracted from the *Bignonia chica* by boiling its leaves in water, decanting the decoction, and allowing it to cool, when a red matter falls down, which is formed into cakes and dried.

The Indian tribes of South America boil the leaves of the chica, and then produce a separation of the fecula by adding pieces of the bark of a tree, common to that part of the world, called *aryana*; it is then washed and formed into round cakes, about 2 inches thick and 5 or 6 inches in diameter, which are dried and considered fit for use. In this state the chica dye is now occasionally met with in commerce; it gives to cotton and woollen an orange-yellow colour.

INDIGO.—This valuable dyestuff is derived from a genus of leguminous plants found in India, Africa, and America, named *Indigofera*. Botanists have described about sixty species of this genus, all yielding indigo; but those from which it is usually obtained are the *I. anil*, the *I. argentea*, the *I. tinctoria*, and the *I. disperma*. It is also extracted from a tree very common in Hindostan (*Nerium tinctorium*), and from the woad plant (*Isatis tinctoria*), which is a native of Great Britain and of other parts of Europe. The colouring matter of these plants is wholly in the cellular tissue of the leaves, as a secretion or juice; not, however, in the blue state in which one is accustomed to see indigo, but as a colourless substance, which continues white so long as the tissue of the leaf remains perfect: when this is by any means destroyed, oxygen is absorbed from the atmosphere, and the principle becomes blue.

In the East Indies, after having ploughed the ground in October, November, and the beginning of December, the seed of the indigo plant is sown in the last half of March or the beginning of April. A light mould answers best; and sunshine, with occasional light showers, are most favourable to its growth; when much rain falls, however, the plants grow too rapidly. Twelve pounds of seeds are sufficient for sowing an acre of land.

As soon as the young plants are sufficiently forward they are replanted in regular parallel rows, care being taken to weed out from the soil any useless parasitic plants.

The plants grow rapidly, and will bear to be cut for the first time at the beginning of July; in some districts even so early as the beginning of June. The indications of maturity are the bursting forth of the flower-buds and the expansion of the blossoms, at which period the plant abounds most in the dyeing principle; another token is taken from the leaves, the breaking across of which, when doubled flat, is accepted as a sign of ripeness; but this characteristic is somewhat fallacious, and depends much upon the poverty or richness of the soil.

The flower-buds are pulled off before they are fully developed, experience having taught that by so doing the leaves of the shrub become larger and yield more indigo, the colouring matter being chiefly in the leaves. In some localities the leaves, which have become bluish green, are pulled from the plant and gathered, but in most cases the entire plant is cut down close to the ground about the months of June or July, when the few flower-buds left have begun to open.

The first cropping of the plants is the best; after two months a second is made; after another interval a third, and even a fourth; but each of these is of diminished value. There are only two cuttings in America.

Two methods are pursued to extract the indigo from the plant: 1. By fermentation of the fresh leaves and stems; 2. By maceration of the dried leaves; the latter process being deemed most advantageous.

In the indigo factories of Bengal there are two large stone or brickwork cisterns, lined with cement, the bottom of the first being nearly on a level with the top of the second, to allow the liquid contents to be run out of the one into the other. The uppermost is called the fermenting vat or steeper; its area is 20 feet square, and its depth 3 feet; the lower cistern, called the beater or beating vat, is as broad as the other, but one-third longer. There are two rows of these tanks. Pure water in large quantity is an absolute requisite in an indigo factory. The water is brought by conduits into large ponds, and after having become clarified by settling, is conducted into large tanks, which are on a level with the masonry tanks just described.

The plant being cut down in the forenoon, is delivered in neatly made up bundles at the factory in the afternoon.

The cuttings of the plant, as they come from the field, are stratified in the steeper till it is filled within 5 or 6 inches of its brim. In order that the plant during its fermentation may not swell and rise out of the vat, beams of wood and twigs of bamboo are braced tight over the surface of the plants, after which water is pumped upon them till it stands within 3 or 4 inches of the edge of the vessel. It is essential that there should be left as little open space as possible, to insure the proper progress of the fermentation.

An active fermentation speedily commences, which is completed within fourteen or fifteen hours, a little longer or shorter, according to the temperature of the air, the prevailing winds, the quality of the water, and the ripeness of the plants. Nine or ten hours after the immersion of the plant the condition of the vat must be examined; frothy bubbles appear, which are at first white, but soon become grey-blue, and then deep purple-red. The fermentation is at this time violent, the fluid is in constant commotion, apparently boiling, innumerable bubbles mount to the surface, and a dense scum of a cupreous hue covers the whole. As long as the liquor is thus agitated it must not be interfered with, but when it becomes more tranquil it is to be drawn off into the lower cistern. Great care is required at this point of the operation, for should the fermentation be pushed too far the quality of the whole indigo is deteriorated; it is even better to cut it short, in which case there is indeed a loss of weight, but the article is better and the returns more profitable. The liquor now possesses a glistening yellow colour, which, when the indigo precipitates, changes to green. The average temperature of the liquid is commonly 85° Fahr.

As soon as the liquor has been run into the lower cistern men are set to work to beat it with oars or paddles, about 4 feet long, called "busquets." Paddle-wheels have also been employed for the same purpose. Meanwhile other labourers clear away the compressing beams and bamboos from the surface of the upper vat, remove the exhausted matter, set it to dry for fuel, clean out the vessel, and stratify fresh plants in it. The fermented plant still appears green, though it has lost three-fourths of its bulk in the process, or from 12 to 14 per cent. of its weight, chiefly water and extractive matter.

The liquid in the lower vat must be strongly beaten for an hour and a half, when indigo begins to agglomerate in flocks, and to precipitate. If the fermentation has been defective much froth arises during the agitation, which must be allayed with a little oil, and then a reddish tinge appears. If large round granulations are formed, the beating is continued to make them smaller, if possible. Should they become as small as fine sand, the water at the same time clearing up, the indigo is allowed quietly to subside. In case the vat was over fermented, a thick fat-looking crust covers the liquor, which does not disappear by the introduction of a flask of oil.

In such a case the beating must be moderated. Whenever the granulations become round and begin to subside, and the liquor clears up, the beating must be discontinued. The froth or scum diffuses itself spontaneously into separate minute particles, which moves about the surface of the liquor, and are marks of an excessive fermentation. On the other hand, a rightly fermented vat is easy to work; the froth, though abundant, vanishes as soon as granulations make their appearance. The colour of the liquor, when drawn out of the steeper into the beater, is bright green, but as soon as the agglomeration of the indigo commences it assumes the colour of Madeira wine; and speedily afterwards, during the beating, a small round grain is formed, the separation of which makes the water transparent, and causes the disappearance of all the turbidity and froth.

In order to hasten the precipitation, lime-water is occasionally added to the fermented menstruum in the progress of beating, but it is not indispensable, and has been supposed to deteriorate the indigo. Two or three hours after the agitation the supernatant liquor is run off, and by its condition affords a good indication of the success of both the processes. A labourer then enters the vat, sweeps all the precipitate into one corner, and empties the liquor into a spout leading into a cistern, situated beside a boiler, 20 feet long, 3 wide, and 3 deep. When all the deposit is once collected it is pumped through a bag, for retaining the impurities, into the boiler, and heated to ebullition, to check further fermentation, which would turn the indigo black. The froth soon subsides, and shows an oily-looking film upon the surface. The indigo is by this means not only freed from the yellow extractive matter, but enriched in the intensity of its colour and increased in weight. Some manufacturers, however, prefer retaining it at a moderate temperature throughout, and affirm that a deeper hue is produced.

From the boiler the mixture is run, after two or three hours, into a general receiver, called the *dripping* vat, or table, which, for a factory with twelve pair of preparation vats, is 20 feet long, 10 wide, and 2 deep, having a false bottom 2 feet below the top edge. This cistern stands in a basin of masonry, made water-tight with hydraulic cement, the bottom of which slopes to one end in order to facilitate the drainage. A thick woollen web is stretched along the bottom of the inner vessel to act as a filter. As long as the liquid passes through turbid it is pumped back into the receiver, but as soon as it runs clear the latter is covered with another piece of cloth to exclude the dust, and percolation is allowed to proceed spontaneously. Next morning the drained magma is put into a strong bag and squeezed in a press. The indigo is then carefully taken out, and cut with a brass wire into pieces of about 3 cubic inches each, which are dried either in a stove upon boards, or in an airy room upon shelves of wicker work. Or, the pasty and still very soft mass which remains upon the cloth is removed to small wooden boxes, perforated with holes, and lined inside with a stout and strong cotton tissue. These boxes having been filled, and a lid having been put on the top, likewise perforated, and so constructed as to fit *in* and not *on* the boxes, care being also taken to place a piece of cotton on the top, the boxes are placed under a screw press, and pressure having been gently and gradually applied, the water is squeezed out as much as possible, the liquid being again run into the filter tank to collect any indigo it may yet contain. The pressure having been withdrawn the boxes are opened, and the contents, shaped like blocks of soap, are placed in the drying room.

The drying should take place very slowly, and it takes from three to five days to dry the contents of each box. During the drying a whitish efflorescence appears upon the pieces, which must be carefully removed with a brush. In some localities, particularly upon the coast of Coromandel, the dried lumps of indigo are allowed to effloresce in a cask for some time, and when they become hard they are wiped and packed for exportation.

The other method of extracting the indigo from the plant differs from that described only in the first operations. Instead of putting the plant into the vat when newly cut, it is spread out to dry in the sun for two days, and then thrashed to separate the leaves from the stems. The former are kept until they have changed from a green to a bluish-grey or lavender colour, after which they are put into the first vat with warm water, and kept stirred till the leaves are so completely wetted as to sink. The liquor is then instantly let off into the beating vat, where it is treated as already described.

Indigo, as it occurs in commerce, is usually met with in cubical lumps or cakes, friable, more or less brittle, and of various shades of a peculiar deep blue, passing into violet purple. When rubbed with a smooth hard body it acquires a beautiful glossy and cupreous appearance, and always affords, on grinding, an intensely blue powder. Its specific gravity is sometimes greater, but at other times less, than that of water; this depends principally on its admixture with or freedom from foreign matters, but also upon the treatment of the paste in the operations of boiling, pressing, and drying. The best samples are those which are lightest in weight and most copper coloured.

The trade in Bengal indigo is chiefly carried on in Calcutta; its varieties are very numerous.

Coromandel indigoes of the best quality correspond to those of Bengal of medium value, and are met with in square masses, having an even facture, but are more difficult to break; indeed, these are harder to disrupture than any other variety. The inferior kinds are heavy, of a sandy feel, having a blue colour bordering on green, grey, or even on black; they are not unfrequently found having a greenish grey hue.

The productions of Madras have a grained rough fracture, and are of a cubical figure. The superior qualities have no rind, and are more light and friable than those of Coromandel. These kinds, when of the best quality, are very light, though not equal in this respect to the superfine blue of Bengal. The middling classes have a very slight copper tinge. The colour of the inferior qualities is a dark or muddy blue, black, or even grey, and greenish.

The Manilla indigoes present the mark of the rushes upon which they have been dried. They are of a closer consistence and lighter hue than those of Madras, but not so compact as the produce of Bengal. The better qualities are often in flat and elongated masses, somewhat porous, and consequently light. Medium kinds are of a violet colour, but are inferior to the violet of Bengal.

Java indigo occurs in flat square masses, sometimes of a lozenge shape. The superior qualities appear as fine as the blue, violet, or red indigoes of Bengal, but they are not so in reality.

The superior classes of Egyptian indigo are superfine and fine violet blues. They are light, but their structure is not very compact, and they often contain sand. The squares are rather flatter than those of Bengal.

Senegal indigoes are of good quality, but contain more earthy matter than any others in the trade.

The indigoes of Guatemala, of the Caraccas, and of Mexico, are of various kinds. The best are a bright blue, remarkably light and fine. These are esteemed equal to the best Bengal. The inferior qualities are of a violet hue, but in general are more mixed than the Bengal kinds.

The Brazil indigoes are in small rectangular parallelopiped masses, or in irregular lumps, of a greenish-grey colour externally, having a smooth fracture, a firm consistence, and a cupreous tint of greater or less brilliancy.

The Carolina product is in small square masses, having a grey exterior. The best qualities have a dull copper colour, bordering on violet or blue. The common kinds are almost always of a greenish-blue; they are rarely found of a cupreous hue.

The following trade terms are in use in the indigo trade:—*Sandy indigo*, containing a large quantity of earthy matter. *Ribbon indigo* has bands of colour of different shades. *Spotted indigo*. *Burnt indigo*, this variety falls to pieces when pressed by the hand. *Large squared indigo*, cakes broken into large lumps. *Half broken indigo*, cakes broken into two pieces. *Coarse granulated indigo*, small lumps. *Cold indigo*, when the substance does not adhere to the tongue. *Fig indigo*, a very low quality used by makers of laundry blue.

Logwood.—*Bois de Campeche*, *Bois bleu*, French; *Blauholz*, German; *Hæmatoxylum*, Latin.—This wood is obtained in great abundance in Jamaica and on the eastern shores of the Bay of Campeachy, and is imported into this country in small pieces or blocks. The wood from the two localities produces different qualities of dye; on this account the name of its habitat is affixed to each, and the two kinds are distinguished in commerce as Campeachy and Jamaica logwood. The former is superior to the latter, and consequently fetches a higher price in the market. The logwood tree is called by botanists *Hæmatoxylum campechianum*. In a favourable position it grows to a very large size. The bark of the tree is smooth and thin, and furnished with thorns, its leaves resembling those of the common laurel. The wood is very hard and close in the fibre, and is capable of taking on a fine polish; it is somewhat heavier than water, and consequently sinks when put into that liquid.

Logwood is very hard and close in the fibre. When used chipped in small pieces it requires long boiling to extract the colouring principle. To obviate this, the wood is now generally ground fine, by a machine such as that already described (see Brazil Wood), by which means the operation is much facilitated. To avoid loss by dust in grinding, owing to the dryness of the wood, it is moistened by water, which greatly enhances the appearance of the wood, by producing a richer colour upon it, and does not affect its dyeing properties.

Madder—*Garance*, French; *Faberröthe*. German—is the root of the *Rubia tinctorum*. It is common in the South of Europe and in many parts of the Levant, and is largely cultivated in Holland; it attains to about 3 feet in height, and has a long spreading fibrous root, which is the part used in dyeing. The best roots are of the size of a writing quill, or, at most, of the little finger. They are semi-transparent, reddish, have a strong odour, a smooth bark, and should be of two or three years growth. The root is taken from the ground, picked, and dried, in order to be ground and preserved. In warm climates it is dried in the open air; elsewhere, stoves are made use of. The stringy filaments and epidermis, termed *mulle*, as also the pith, are removed, leaving nothing but the ligneous fibres.

The roots are dried in a stove heated by a furnace, from which the air is allowed to issue only at the moment when it is judged to be saturated with aqueous vapour. Above the furnace flue, which occupies a great portion of the floor, are three gratings, on which the roots are arranged in layers of about 8 inches. At the end of twenty-four hours, those on the first grated floor directly above the stove are dry, and are taken away and replaced by those of the higher floors. The dried roots are then thrashed with a flail, passed through fanners similar to those employed for corn, and shaken upon a coarse sieve. The finer particles are again winnowed and passed through a still finer sieve. These operations are repeated five times, using sieves successively finer and finer, and putting aside each time the portion which remains on the sieve. The matter which finally passes through is rejected as sand and dust. After these manipulations, the whole of the fibrous substances remaining are cleaned with common fanners, and all foreign matters, which had not been before removed, are now separated. The roots are then divided into different qualities, for which a brass sieve is used, the meshes of which are from one-fourth to one-eighth of an inch in diameter. The finest portion is rejected, while the coarsest is considered of the best quality. These roots, thus separated, are carried into a stove of a construction somewhat different from the first. They are spread out in layers of about 4 inches in thickness, on large lattice-work frames, and the drying is known to be complete when, on taking up a handful and squeezing, the roots break easily. On quitting the stove the madder is placed, still hot, into a machine, where it is cut small, and the portion of the bark reduced to powder is separated. This operation is repeated three or four times, after which resort is had to the bolter. The madder which passes through the brass meshes of the bolter is considered as common, and that issuing from the extremity of the bolter is called the flour. Lastly, the madder, after being subjected to these processes, is ground in a mill with vertical stones, and afterwards passed through sieves of different degrees of fineness. The madder of Alsace is reduced to a very fine powder, and it requires a much longer boiling to extract its tinctorial matter than is necessary for the "lizari" of the Levant. The prepared madders ought to be carefully preserved from humidity, as they readily imbibe moisture, in which case fermentation injures their colour. D'AMBOURNEY and BECKMANN consider that it is better to employ the fresh root of madder than that which has been stove-dried.

In commerce, the name of "lizari" has for a long time been restricted to the entire roots of the madder, while that of "madder" is applied to the pulverized roots.

Lizari is very little employed for the purposes of dyeing, and there is hardly any but that of Avignon which is met with in the markets of France.

Dutch madder has a strong and nauseous odour; its taste is sweet, but with a mixture of bitterness; its colour varying according to the marks, and passing from a brownish to an orange-red. The brownish-red tint, however, is applicable only to the "mulle" madder of each kind. The term "mulle," or "bilon," is applied to the inferior quality of madder, which consists of a mixture of the smallest roots, of the fibres and epidermis of the larger roots, of earthy matters, and of the refuse from the sieves.

In general, its powder is stringy, that is to say, its state of division is sufficiently large to exhibit the structure of the root. Exposed to the action of the atmosphere it readily absorbs moisture, and when, for the sake of ascertaining its quality, it is exposed to humid air, its orange-red becomes bright, rich, and deep. This madder, to use a commercial term, "works" more than others: that is, it presents more decided modifications of colour on exposure to moisture.

Dutch madder is either stripped or the contrary. In the first case, the roots have been freed from their epidermis, which gives greater brightness to the powder; in the second, they have been triturated without undergoing this operation, when the powder is of a more sombre hue. This madder cannot be used while fresh; it must at least be a year in the cask.

The *pale* powder, or that of the first year, having a yellow aspect, soon undergoes fermentation; the divided particles then unite with each other, agglomerate, and increase in volume to such a degree that, after from one to two years, the dilation is so great, that the bottoms of the casks present a very marked convex form. The madder is then so hard that, in order to take it out of the cask, a mallet or chisel must be used.

It keeps several years after having attained its greatest tinctorial power; but after about three years the layers which line the sides of the casks then begin to lose their brightness; the madder assumes a pale-brown colour, and enters into decomposition, the process of which is slow but certain; it subsequently becomes quite extinct, and the madder has a brown-red hue. When partially decomposed it may still be used for brown grounds or light colours; but when age has affected all the tinctorial principles it can only serve as "mulle." The term "grappe," signifying bunch, is employed when age has given consistence to the powder, and designates its state of agglomeration.

Alsatian madder has a penetrating smell and a bitter taste, and its colour varies from brown to bright yellow. It easily absorbs moisture from the atmosphere by exposure, and changes from yellow to a dark red.

It is not employed while fresh, and is in the best condition when about two years old.

Madder of Avignon is most generally used at the present time, and even preferred to the other kinds, because the dyer and the calico-printer find it easier to modify the reds according to wish.

The characters of this powder are—odour agreeable, slightly penetrating; taste, sweetish bitter: colour, either rose, bright-red, or brown-red, according to the roots employed in the preparation, and to the degree of mixture; state of division very fine; powder dry to the touch.

When submitted to the action of the atmosphere, it absorbs moisture less readily than the other species, but it does not work less, and subsequently affords a pale or very dark red, according to whether the powder operated on was "rosy" or "palus."

In Avignon, the name *Palus* is given to some tracts of land anciently covered with marshes; these grounds, enriched by animal and vegetable remains, are eminently suited for the cultivation of madder; the roots they produce being almost all red, and of a superior quality; whilst other kinds of soil yield rose-coloured roots.

The powder from the palus madder is of a rather unsightly red, but on drying it becomes blood-red, and the shade may be varied at pleasure.

The powder from the "rosy" is of a bright red, bordering a little upon yellow.

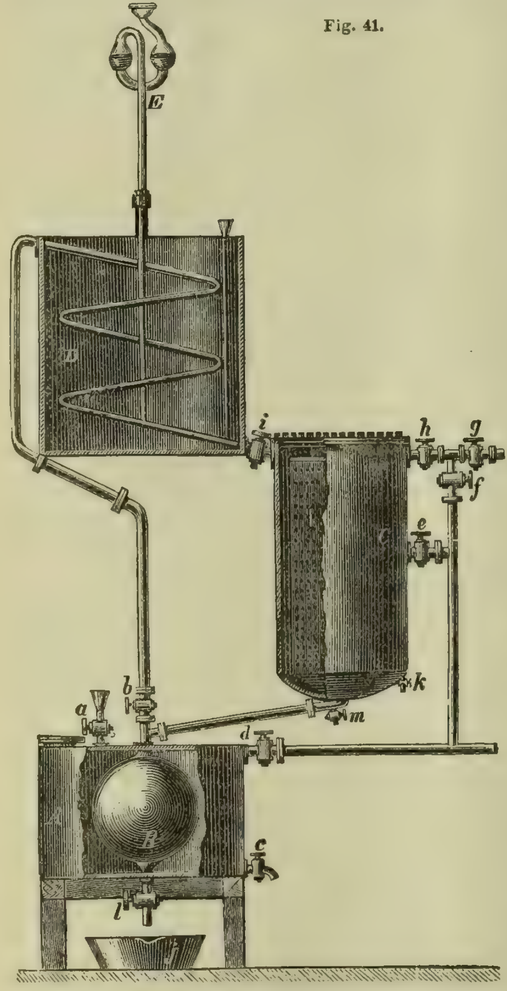
Avignon madder may be used immediately on leaving the mills; but that which has been preserved in casks for a year is decidedly preferable. It keeps well, and undergoes little or no fermentation; it does not cohere in a mass; after several years, however, it is decomposed with nearly the same symptoms as the other kinds: but is still fit for use.

MALVACEÆ.—The petals of the plant known as *Althæa rosea*, belonging to the natural order *Malvaceæ*, contains a peculiar colouring matter, soluble in water and alcohol, but insoluble in ether. The aqueous solution of the petals, freed previously from the calix and stamens, exhibits a violet-red colour, which is turned crimson by the addition of acids and green by alkalies. The alcoholic tincture of the leaves is purplish red, and leaves on evaporation a deepened residue, free from nitrogenous matter.

Cotton mordanted with iron is turned blue or bluish black by an aqueous infusion of the petals. With an aluminous mordant a violet blue, and with tin mordants a bluish violet, is produced.

Woollen fabrics, previously mordanted with bichloride of tin, assume a deep violet, and when mordanted with iron a bluish black or grey; if mordanted with antimonic acid salts, a bluish violet is obtained.

Fig. 41.



Silk mordanted with tin salts takes a violet.

For calico printing the alcoholic extract suits better than the aqueous infusion. The apparatus employed by E Kopp to prepare the alcoholic extract is shown in Fig. 41. The flowers are placed in a vertical wire-work cage, I, which is contained in the steam-jacketted cylinder, C. A pad of woollen cloth is then placed above the flowers, and the whole closed in by a tightly fitting iron plate. The spirits of wine are contained in the globular retort, B, placed in the cast-iron steam chest, A. The alcohol is volatilized by steam conveyed into A, through the tap, *d.* The alcohol vapour passes through the tap, *b*, into the condensing worm in the cold-water cistern, D, and is then forced under the pressure of the mercury contained in the pressure tube, E, through the tap, *i*, into the wire cage containing the flowers. The steam jacket, C, is at the same time heated by steam passing through the tap, *e*. The extract flows back into the retort, B, where it is caused to part with its spirit, which makes another circuit of the apparatus. The tap, *m*, serves to take samples. When the operation is judged to be completed, the taps, *d*, *e*, and *i*, are closed, and the tap, *a*, opened, in order to clear the steam chest, A, of steam. The taps, *f* and *h*, are next opened, in order by a momentary rush of steam to drive over the last remnants of alcoholic extract. The tap, *f*, is then closed, and the taps, *g* and *l*, opened, upon which the extract flows into the receptacle, *j*. The taps, *k* and *c*, are to run off condensed water when necessary.

Safflower; *Bastard Saffron*, *Carthamus*, *Carthamus tinctorius*. It is a native of Egypt, and the warmer climates of Asia. It has been cultivated in Europe, near Alsace, and also around Lyons. The Chinese have long known its use, and produce from it their finest red. The colour called by them *bing*, which is used by the Japanese ladies as a cosmetic, is made from it, and is kept in little porcelain cups similar to those retailed in this country as *pink saucers*.

It is obtained mostly from the East Indies and Turkey; the former is considered the best.

The *Carthamus tinctorius* is an annual plant, with an upright, firm, smooth stem, of a light grey colour. It grows to about 3 feet in length, when it divides into several branches, bearing leaves of an oval form, and edged with small spines. Each of the branches is terminated by a large flower-head, composed of several flowerets of a deep red colour. The plant is propagated by seeds, which are sown early in spring. It is from the flower that the dye is obtained; the richest colour is produced when the flowers are gathered before being fully blown. When collected, they are dried in the shade, and carefully preserved from any moisture, which would injure the colour.

As soon as the flowers are collected they are pressed between two stones, so as to deprive them of a portion of their juice; they are then washed several times with spring water, which contains a little common salt in solution. On being taken out of the water they are pressed between the hands, and then spread out on mats upon terraces, and allowed to dry slowly, being covered by mats during the day and exposed again at night. They are turned over from time to time, and when found to be properly dried are preserved for sale.

Safflower is found in the market in dry hard cakes. To prepare it for dyeing, a quantity of these cakes are steeped in clean cold water. Hard or spring water is preferable for this purpose. A cover is put upon the top of the cakes, and is subjected to a gentle pressure to keep them under the water. They are allowed to lie in this condition till thoroughly wet and penetrated by the water, when the cakes expand and open up, under the influence of the moisture, into fine fibres. The whole is now removed by small quantities at a time, and placed upon a fine hair sieve, when water is passed through until it ceases to be coloured yellow. The washings are allowed to flow away, and the red fibres are then placed into a vessel sufficiently large to hold a gallon of water for each pound of safflower. To this water is added from 3 to 4 ozs. of carbonate of potash or soda for each pound of safflower; the whole is well stirred, and the stirring repeated every half hour. After six or seven hours the safflower has lost its red colour, and has acquired a dun tint; the whole is again passed through a hair sieve; but on this occasion the liquor passing through is carefully preserved, as it contains the dye; a little clean water is poured over every sieve-charge of the exhausted fibre, to wash out all colouring matter. The fibre is then pressed as dry as possible, and thrown away. The liquor has now a brownish-red colour, and is ready to dye cotton.

TURMERIC.—Turmeric, or Indian saffron, is a yellow dye obtained from the roots of *Curcuma longa*. This plant is indigenous to the East Indies and other parts of Asia, and to Madagascar. It has been cultivated with some success in Tobago, and samples from that island have been found superior to that usually imported from India. Our supplies are brought from the East Indies, China, and Java; of these, the Chinese turmeric is the best.

The roots of the *Curcuma longa* spread far into the ground; they are long and succulent, and about half an inch in thickness. These roots are externally of a colour inclining to grey, but internally of a deep yellow colour; they are reduced to powder previous to being employed as a dye.

WELD or WOLD is a biennial plant, called by botanists *Reseda luteola*. This plant is well known throughout Europe, and is indigenous to England; it is found growing wild in many parts of the country, and was once cultivated for its colouring produce in several counties of England, such as Kent, Herefordshire, and near Doncaster, in Yorkshire. It is very extensively cultivated around Paris, and in other parts of France. The plant, after being gathered, is carefully dried and tied up in bundles, in which state it is sold to the dyer.

WOAD—*Isatis sativa*—is a plant known and used for the purposes of dyeing from the earliest times. The ancient Britons, when invaded by the Romans, are described as having their bodies stained with the colouring matter of this plant. It is cultivated in the Azores and the Canary Islands, in Italy, in Switzerland, in parts of Germany, Sweden, and in various districts of France. It is likewise indigenous to England, and is still cultivated in Lancashire. For many centuries it was a most important branch of British industry. It is still used as a dye for blue in woollen and silk stuffs, often, however, accompanied with indigo, the colouring matters of these substances being similar. A superior quality of this dye, which is principally produced in the South of France, is known in commerce by the name of *Pastel*.

The *Isatis sativa* is a biennial plant, having a large woody root, which penetrates deep into the ground; the stem is from 3 to 4 feet high, and about half an inch thick, divided into several branches. Three or four crops are usually obtained in one year. The plants are mowed with a scythe, and as soon as collected are washed in a stream of water and dried in the sun. This must be rapidly done, otherwise the woad will be impaired in quality. When dried, it is conveyed to a mill and ground into a smooth paste, which is laid in heaps, pressed close together, and covered to protect them from rain. If any crack appear in these heaps, care is taken to unite them, as that would also impair the quality of the woad. After remaining for a fortnight in heaps, the paste is rubbed together and formed into solid balls, which are pressed into a compact substance in wooden moulds and dried Good balls are distinguished by their superior weight, and by having a violet colour within. These balls are further prepared for dyeing by being beaten with wooden mallets on a stone floor until they are reduced to a coarse powder, which is then heaped up in the middle of the apartment and moistened with water. Fermentation arises, and after about twelve days it is pretty well dried by being turned over, and then it is made into a heap for the use of the dyer.

PRACTICAL OPERATIONS.—For many of the receipts herein contained we are indebted to the *Moniteur de la Teinture*, *Reimann's Färber-zeitung*, *Muster-zeitung*, *Chemical Review*, *Dingler's Polytech. Journal*, &c., &c.

The dye woods may be used either (*a*) in the state of cold infusions, made by steeping the ground wood in water without the application of heat; or (*b*) in the state of a weak extract, made by putting upon a coarse flannel strainer 1 lb. of the ground wood for each gallon of liquid required, and pouring over the same boiling water till the liquor runs through nearly colourless; or (*c*) as a concentrated liquor or extract, marking from 8° to 24° Tw.; and, lastly (*d*) as a solid extract, formed by evaporating the liquid extract down to dryness. It must not be supposed that the properties of these four different states are identical. Where bright light shades are required, (*a*) or (*b*) will be found preferable; whilst for heavy shades, especially of sad colours, (*c*) and (*d*) should be employed. For all purposes where great concentration is needed (*a*) and (*b*) are, of course, inadmissible.

Barwood, camwood, and red sanders are always used in the ground state, the wood being put into the dye beck along with the goods.

To prepare Annotta. — Into 2 gallons of water put 1 lb. annotta, 4 ozs. pearl-ash, and 2 ozs. soft soap, and apply heat, and stir until the whole is dissolved. When convenient it is best to boil the solution.

To prepare Catechu.—To 7 or 8 gallons of water put 1 lb. of catechu, and boil till all is dissolved; then add 2 ozs. of sulphate of copper, and stir, when it is ready for use. Nitrate of copper may also be used, taking one wine glassful of the solution prepared as under:—To 1 part by measure nitric acid, and 2 parts water, add metallic copper so long as the acid will dissolve it, then bottle the solution for use. Perfectly distinct and valuable results may be obtained by grinding and extracting with cold water. Very fine greenish drabs are thus produced. The part insoluble in cold, if boiled, yields shades differing from those given by the decoction of the entire ware.

Sulphate of Indigo.—The indigo must be broken into small pieces about the size of hazel nuts, covered with water, and left in steep for about twenty-four hours. It is then reduced to a fine paste in a mill Fig. 42 is an indigo mill in which the colour is ground by cannon balls, *c*, which traverse an iron channel, being forced round by the pallets, *x*, *y*, firmly attached to the axle, *l*, by a framework. *e* is a handle which rotates the arrangement by means of the cogwheels, *n* and *m*. To secure regularity of motion, two heavy globes, *o o*, are screwed on the central axle at *r*, and made to rotate with it.

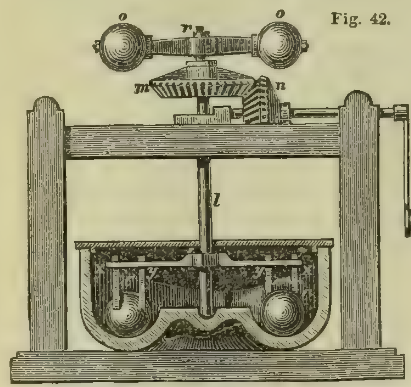


Fig. 42.

Another form of indigo mill is given in Figs. 43 and 44. The vessel, *a*, is a four-sided iron tank, 2 feet 11 inches long, 19 inches broad, and 18 inches deep, cylindrical or rounded in the bottom, and resting upon gudgeons in a wooden frame. It has an iron lid, *b*, consisting of two leaves, between which the rod, *c*, moves to and fro, receiving a vibratory motion from the crank, *d*. By this arrangement a framework, *e*, can be made to vibrate about the axis, *e'*, and to impart its swing motion to six iron rollers, *f*, *f*, *f*, four inches in diameter, three of which are on each side of the frames. These triturate the indigo into a fine paste. This mill is capable of grinding 1 cwt. of indigo at a time. So soon as the paste is uniformly ground, it is drawn off by the tap, *g*, which had been previously stopped by a screwed plug, in order to prevent any of the indigo from lodging in the cock, and thus escaping the action of the rollers.

Fig. 43.

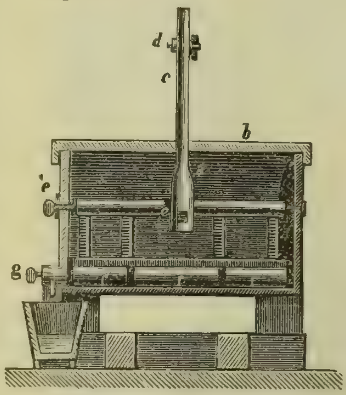
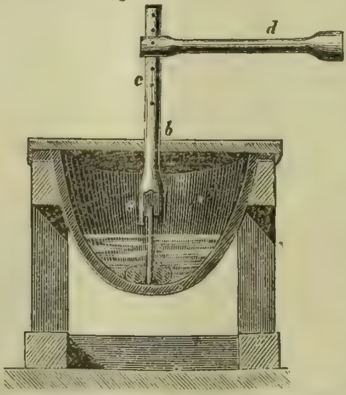


Fig. 44.



To make the sulphate of indigo: into 5 lbs. of the most concentrated sulphuric acid stir in by degrees 1 lb. of the best indigo, finely ground; expose this mixture to a heat of about 160° Fahr. for ten or twelve hours, stirring it occasionally; a little rubbed upon a window pane should assume a purple-blue colour.

This preparation is now sold in the market in the state of a paste, under the name of *Indigo Extract*, which is prepared by proceeding exactly as stated for sulphate of indigo, and then diluting with about 4 gallons of hot water, after which the whole is put upon a thick woollen filter, over a large vessel, and hot water poured upon the filter until it passes through nearly colourless; the blackish matter retained upon the filter is thrown away, and the solution passed through is transferred to a leaden vessel, and evaporated to about 3 gallons, to which is added about 4 lbs. chloride of sodium, and well stirred; the whole is again put upon a woollen filter and allowed to drain. The extract remains as a thin pasty mass upon the filter, and is ready for use.

The solution of indigo in sulphuric acid, without any further addition, is known as "chemic" or "sour extract." It is generally made from refined indigo. The paste extract, where more or less of the acid is neutralized by the addition of carbonate of soda, is called "sweet" or "free extract." Finally, if the sulphuric acid is entirely neutralized, the product is a dry powder, and is sold as "soluble indigo," occasionally as "free extract," and on the Continent very frequently as "indigo carmine"—a misleading name. In any extract of indigo it is essential that all the indigo should be perfectly dissolved. Any particles which may escape solution are very apt to produce specks on the dyed goods. It is also requisite that the green and brown colouring matters naturally present in the indigo should have been removed. The more acid extracts are employed in wool and worsted dyeing, whilst the more neutral modifications serve for silks.

These preparations of indigo are now very rarely employed for the production of pure blues, for which purpose they have been eclipsed by the aniline blues. Their chief scope is now in compound colours. There is hence the less need for a detailed account of the precautions necessary to obtain them in perfection.

To make Red Liquor.—Into 1 gallon hot water place 2 lbs. of alum; dissolve in a separate vessel 2 lbs. acetate of lead in 1 gallon of water; in a third vessel dissolve half a pound crystallized soda; mix all the solutions together and stir well for some time, then allow to stand over night; decant the clear solution, which is ready for use.

Caustic potash and soda can now be readily purchased on the large scale and of good quality. They are now consequently rarely prepared even in the largest dye works.

To Make Lime-Water.—Take some well and newly-burned limestone, and pour over it some water so long as the stone seems to absorb it, and allow it to stand; if not breaking down freely, sprinkle a little more water over it. A small quantity is best done in a vessel, as an old cask, in which case it may be covered with a board or bag. After being slaked, add about 1 lb. of this to every 10 gals. of cold water, then stir well and allow to settle; the clear liquor is what is used for dyeing. This should be made up just previous to using, as lime-water standing attracts carbonic acid from the air, which tends to weaken the solution.

To Make Bleaching Liquor.—Take a quantity of bleaching powder, and add to it as much water as will make it into a thin cream; take a flat piece of wood, and break all the small pieces by pressing them against the side of the vessel, then add 2 gals. of cold water for every pound of powder; stir well, put a cover upon the vessel, and allow the whole to settle. This will form a sort of stock vat for bleaching operations.

To Make a Sour.—To every gallon of water add 1 gill of sulphuric acid, stir thoroughly; goods steeped in this should be covered with the liquor, as pieces exposed become dry, which deteriorates the fibre; if left under the liquor, the cloth is not hurt by being long in the sour; but on being taken out every care should be taken to wash out the liquor thoroughly, otherwise the goods will be made tender.

To Make Cochineal Liquor or Paste.—Put 8 ozs. ground cochineal into a bottle, and add to it 8 ozs. by measure ammonia and 8 ozs. water; let the whole simmer together for a few hours, when the liquor is ready for use.

To Make Iron Liquor.—See ACETATES, or small quantities may be made as follows:—Put pieces of iron, or filings, into pyroligneous acid, and allow it to stand for several days, stirring occasionally; a gentle heat assists the action.

To Make Nitrate of Iron.—Place in a good-sized cask, holding not less than 130 gals., one quarter ton of clean copperas, free from damp. Pour upon it 130 lbs. of double aquafortis at 65° Tw., and stir up the whole well that the acid may touch every portion of the copperas. To avoid injury from inhaling the fumes, the cask should stand in an open shed or under a draught-hood connected with a chimney. In the evening stir up again, not with a violent circular motion, but seeking to turn over all the copperas from the bottom. The next day stir in the same manner both morning and evening, and again in the morning of the third day. The third night the copperas will be found totally dissolved, at most a few pounds remaining. The liquid is let down with water to about 80° Tw., stirred up, let settle, and bottled off. Like all varieties of nitrate, or rather nitro-sulphate of iron, it must be screened from light and preserved from extremes of heat and cold. This quality is well adapted for dyeing a blue with prussiate upon cotton yarns and unmixed cotton pieces. For mixed piece goods it should not be used.

For a nitrate of iron for blacks the same process may be followed, but the double aquafortis should be reduced to 120 lbs. per quarter ton of copperas. Some dyers prefer to add to black nitrate of iron a proportion of brown acetate of lead (crude sugar of lead), which should not reach 70 per cent. of the weight of the copperas originally employed.

A nitrate of iron for sky-blue, or for conversion into green by topping with a yellow dye, may be made by letting down common aquafortis with water to 32° Tw. To this clean scrap iron is then gradually added as long as it is dissolved with the escape of an orange gas. The solution, when saturated and cold, stands about 43° Tw.

For full bloomy royal blues on the cotton warps of mixed piece goods the following formula may be used:—Dissolve 16 lbs. nitrate of soda in 13 gals. of water. Weigh out 20 lbs. of oil of vitriol, and add it by degrees, along with as much clean scrap iron as is needed. Do not let the mixture get too hot. This nitrate should not be made in large amounts at once, as it soon deposits a sediment, especially in hot weather. The presence of muriatic acid is very objectionable in any nitrate of iron employed to dye mixed goods, as it has the tendency to throw the iron upon the wool or worsted.

The following compound, which is an "iron alum," is used and recommended by some dyers:—Dissolve 78 lbs. red oxide of iron in 117 lbs. sulphuric acid; let down with water; add 17 lbs. of sulphate of potash, and let crystallize.

To Make up a Blue Vat.—Take 1 lb. of indigo, and grind in water until no grittiness can be felt between the fingers; put this into a deep vessel—casks are generally used—with about 12 galls. of water; then add 2 lbs. copperas and 3 lbs. newly-slaked lime, and stir for fifteen minutes; stir again after two hours, and repeat every two hours for five or six times; towards the end the liquor should be of a greenish-yellow colour, with blackish veins through it, and a rich froth of indigo on the surface. After standing eight hours to settle, the vat is fit to use.

PREPARATION OF SPIRITS.—Although most if not all the mordants required in dyeing may be purchased, it is very important for the dyer to be acquainted with their preparation.

Single Muriate of Tin.—Dissolve grain-bar tin, previously feathered or granulated, in commercial muriatic acid, till the specific gravity rises to 50° to 60° Tw. The strength of the acid to begin with is generally 32° Tw. In some establishments it is let down with water to 20° or 22° Tw. before adding the tin, in which case a greater amount of metal must be dissolved to bring the solution up to any required strength. It contains from 1 to 2 ozs. of tin to the lb.

Double Muriate of Tin is sometimes erroneously supposed to be a persalt. It is merely a solution of the protochloride, like single muriate, but of greater strength, ranging from about 70° to 120° Tw., and containing from 2½ to 5 ozs. metallic tin per lb. The weaker qualities, at from 70° to 90° Tw., are used in woollen dyeing; and the stronger, which of course contain a relatively smaller proportion of acid, for cotton dyeing.

Some of the most useful mixtures of muriate of tin with other acids are the following:—

Bancroft's Scarlet Spirit.—Mix spirits of salt at 32° Tw., 2 lbs; oil of vitriol, 3 lbs.; and dissolve 14 ozs. in the mixture. This spirit is in less demand than formerly, as the grain and lac scarlets dyed with it generally take a somewhat brownish shade.

Yellow and Orange Spirit.—Mix oil of vitriol, 2 lbs.; water, 2 lbs. When cool add the mixture to 5¾ lbs. good double muriate. On this spirit W. CROOKES remarks that the more tin and the less free acid exist in the muriate the more the cloth will exhibit a beautiful greenish reflection if held up to the light and viewed horizontally.

Another Yellow Spirit.—Spirits of salts, 3 parts; oil of vitriol, 1 part; water, 1 part; feathered tin, as much as it will take up. Care must be taken that whilst the tin is dissolving the heat shall not rise above 60° Fahr.

Amaranth Spirit.—Spirits of salt, 95 lbs.; oil of vitriol, 5 lbs.; mix, and dissolve 4¾ lbs. of tin. This preparation is used by some dyers for reddish-violet wood shades.

Scarlet Finishing Spirit.—Take 3 pints muriate of tin at 54° Tw., and add 2 ozs. oxalic acid, dissolved in hot water enough to bring the mixture to 40° Tw.

It is used for raising cochineal or lac scarlets which have been previously grounded with the "bowl spirit" or "nitrate of tin" to be mentioned below. Some dyers replace half the oxalic acid directed with tartaric acid. In some establishments this spirit is employed for scarlets at once, without the previous grounding with nitrate of tin, and without tartar. This method is used for hard worsted trimmings. For softer materials the strength of the muriate may be preferably 60° or 70° Tw. This variation is especially adapted for cochineal oranges, maizes, and similar shades.

Another Receipt.—Add to 4 gals. muriate of tin at 54° Tw. 1 pint oil of vitriol, previously mixed with 3 pints of water, and allowed to cool. Then dissolve 1 lb. of oxalic acid in a gallon of water, and add the solution to the other ingredients. Tartar is required when this spirit is used in dyeing scarlets.

Puce Spirit.—Take 4 gals. muriate of tin at 70° Tw., and add 2 gals. of sulphuric acid previously let down with water to 28° Tw., and let cool.

Oxalate of Tin.—The mordant commonly so named is really a muriate of tin, to which oxalic acid, oxalate of potash, and generally sulphuric acid, have been added in very variable proportions.

It may be made by adding 1 oz. of oxalic acid, dissolved in hot water, to 1 gal. of the "puce spirit," just mentioned. It is employed as a royal blue finishing spirit for blooming blacks, as a scarlet spirit with cochineal or lac, and as an orange spirit, with cochineal and flavin or young fustic. Where extra brightness is required, the oxalic acid may be increased to 2 ozs. per gallon. Such an increase is not required for topping blacks.

With the exception of the stronger kinds of double muriate, the above-mentioned preparations are used in woollen dyeing, and are not suited for vegetable fibre.

Tin crystals, the solid muriate of tin, are obtained by evaporating down the strongest solution of the metal in muriatic acid till it crystallizes. The crystals are generally sold in stoneware jars, containing from 2 to 3 cwts., and should be protected as far as possible from contact with the air. They generally form a somewhat milky solution with water, which, however, becomes clear on the addition of a few drops of muriatic acid. They are sometimes adulterated with sulphate of magnesia or sulphate of zinc, a fraud which is easily detected by dissolving a small portion of the sample in pure muriatic acid, diluting with distilled water, and adding a little of a solution of the chloride of barium. If any sulphate is present a white turbidity is occasioned. If it be required to find the quantity of tin present in either tin crystals or single or double muriate it may be ascertained as follows:—Weigh out 100 grs. of the sample, and mix them with 20 ozs. pure water, and half an oz. of muriatic acid. Dissolve in hot water 83½ grs. pure bichromate of potash, and fill a burette with the solution. Drop this liquid from the burette into the solution of tin, which gradually turns green. Continue adding the bichromate solution very gradually until a drop taken out, and placed upon a white saucer, gives a yellow colour when tested with a drop of the solution of acetate of lead. Every degree of the burette consumed until this effect is produced represents 1 gr. of metallic tin in the weight of the sample operated upon.

Tin crystals are used for very much the same purposes as the stronger kinds of double muriate. They are also frequently employed along with a mixture of nitric and muriatic acids, or with chlorine gas, in preparing the persalts of tin, stannic chloride or tin perchloride, in a state of greater or less purity.

The sesquisalts of tin, which we next mention, are used both for animal and vegetable substances.

Nitrate of Tin, otherwise known as "scarlet spirits" and "bowl spirit," is prepared as follows:—Into a large clear bowl is put a known weight of so-called "single aquafortis," a kind specially prepared for this use, marking from 32° to 34° Tw., and perfectly free from sulphuric acid and from nitrous fumes. It contains, however, a certain proportion of hydrochloric acid, which is absolutely necessary for this use. Grain-bar tin of the best quality, and in the rod, not feathered, is weighed out in the proportion of 1 lb. metal to 8 lbs. of acid. A number of these rods, varying according to the temperature and to the make of the acid, are put in and allowed to dissolve. In average weather four or five rods may thus be entered. In a short time, if the operation is rightly conducted, the liquid, which was previously colourless, "turns," that is, assumes a deep amber colour. The remainder of the tin is then gradually added, taking care that the action does not become too violent, and that no bubbles of orange-coloured gas are formed. In hot weather one or two bars are quite sufficient in the outset, whilst in frost eight or ten may be needful. If the temperature is very high half a pint of nitrate of tin from a previous lot should be added to the aquafortis at the outset, and the spirit may then be started with a handful of clean and dry feathered tin. Rods are then gradually added when the process has been fairly commenced.

This spirit has an amber colour. It should mark from 58° to 60° Tw., and contain $2\frac{1}{4}$ to $2\frac{1}{2}$ ozs. of tin per lb. It is used both for woollen and cotton dyeing.

Purple Spirit (for certain woad purples upon woollens and worsteds).—Take nitrate of tin as above described, freshly made and good. Set the bowl containing it in a larger vessel of hot water, and add as much grain-bar tin in the rod as it will dissolve. It should stand at about 80° Tw.

Aniline Spirit.—Mix 5 gallons of single aquafortis at 32° Tw., with half the quantity of muriatic acid at the same strength, and enter gradually 12 lbs. of best grain bar tin, not feathered. Do not let the mixture get very hot. This spirit contains nearly 2 ozs. metallic tin to the 1 lb. of mixed acids, and if properly worked will be of a dark amber colour. It gives a white precipitate, which quickly turns black. The resulting liquid, sometimes mixed with oxalic acid, is used by some dyers for dyeing cochineal scarlets, and gives good results.

The persalts of tin, used chiefly in cotton and silk dyeing, are prepared either by dissolving the metal in a mixture of nitric and muriatic acid in which the latter predominates, or by dissolving tin crystals in a similar manner. The compounds obtained in these methods are apt to vary. The nitric acid is never entirely expelled, and appears to combine with some of the tin and to modify its action. Further, a part of the tin generally remains in a state of protosalt (stannous chloride). To obtain a pure perchloride of tin (stannic chloride), the most effectual process is to dissolve tin crystals in the very smallest possible quantity of muriatic acid, and to pass chlorine gas through the solution till a drop taken out and mixed with a solution of the perchloride of mercury (corrosive sublimate) no longer gives a white precipitate which turns black on standing. A pure perchloride thus obtained can be either used alone as a mordant or may be mixed with the muriate (protochloride) in any required proportion, and the effects thus obtained can always be exactly reproduced. Still there are cases where the spirits made with mixtures of nitric and muriatic acids produce peculiar and desired effects, and we therefore give a selection of receipts for their preparation.

Red Cotton Spirits.—

Muriatic acid at 32° Tw.,	7 gals.
Double aquafortis at 62° Tw.,	1 "
Water,	1 "

Tin in the rod is then gradually added till 6 lbs. have been dissolved. Avoid excess of heat. The amount of muriatic acid may be reduced as low as 3 gallons, different proportions producing a spirit suitable for different colours.

A somewhat different spirit is made with—

Muriatic acid at 32° Tw.,	17 gals.
Double aquafortis at 62° Tw.,	3 "
Tin enough to raise the strength to 54° Tw.	
Bichrome,	2 ozs.

It is chiefly used for the cotton warps of mixed goods which are to be dyed in aniline colours, or are to receive certain compound shades, such as clarets, from the woods.

Various preparations are used as mordants, which consist chiefly of stannic chloride or tetrachloride of tin, formerly known as bichloride. They figure in technological works and in trade catalogues under many names, such as "composition," tin-solution, oxymuriate, permuriate, nitro-muriate, &c.

Barwood Spirit—

Muriatic acid,	5 gals.
Double aquafortis,	1 "
Tin, 1 oz. per lb. of the acids.	

Plum Spirit—

Muriatic acid,	6 gals.
Double aquafortis,	1 "
Tin, $1\frac{1}{2}$ oz. per lb.	

The so-called plum tub is made by adding from 1 pint to $1\frac{1}{2}$ pint of plum spirit to a gallon of strong logwood liquor. It dyes silks and cottons without any further preparation, and was formerly in great demand, but since the introduction of the aniline violets and purples it has fallen very much into abeyance as far as silks are concerned.

Purple Cotton Spirits—

Muriatic acid,	5 lbs.
Double aquafortis,	1 "
Tin, 2 ozs. per lb.	

Pansy Spirit—

White argol,	5 lbs.
Granulated tin,	5 "
Muriatic acid,	5 "

Add 15 lbs. oil of vitriol, previously diluted with a gallon of water, and finally add very gradually 2 lbs. of double aquafortis.

Chemical analysis throws very little light upon the practical value of these compound spirits, the mere amount of tin being of less importance than its condition. The greater or less speed with which the tin is added to the acid, and the temperature attained, greatly affect the quality of the result. If the heat be too great, a part of the tin is often deposited in an insoluble and useless state, and even when this does not happen, its affinity for the fibre is often destroyed. Spirits which have been injured in these manners are said to have been "fired."

Aceto-nitrate of Chrome.—Select a stone-ware bowl holding 30 litres, and set it upon supports in the open or under a draught-hood, so that it may be gently heated. Put into it 3 kilos. of chromate of potash in coarse powder, 4·4 litres of boiling water, 2·6 litres of nitric acid, at 36° B. Mix well together, and add gradually 0·72 litre of white glycerine at 28° B., and 4·28 litres acetic acid at 7° B. When all is dissolved, pour into a double-bottomed pan, and heat rapidly to a boil by means of steam. This is kept up until the liquid appears of a pure green in thin layers. It is then allowed to cool in a stone-ware bowl, decanted, and the deposit of saltpetre is washed with 0·8 litre of cold water, and the washings added to the first part of the liquid.

For Copperas.—See *Iron Salts, ante.*

For Blue-Stone—sulphate of copper.—See *Copper Salts, ante.*

In making solutions of these salts, such as copperas, blue-stone, chrome, &c., there is no fixed rule to be followed. A quantity of the crystals are put into a vessel, and boiling water poured upon them, and stirred till dissolved. Some salts require more water than others when saturated solutions are wanted; but in the dye house a certain degree of saturation is not essential, and therefore there is always used ample water to dissolve the salt. In all cases, however, the proportions are known, so that the operator, when adding a gallon or any quantity of liquor to the dye bath, knows how much salt that portion contains. From a half to 1 lb. per gallon is a common quantity.

To Remove Oil Stains.—When oil spots are upon goods, and so fixed or dried in that steeping in an alkaline lie will not remove them, rub a little soft soap upon the oil stain, and let it remain for an hour, then rub gently with the hand in a lather of soap, slightly warmed, and then wash in water; for cotton, a little caustic lie will do equally well for removing the oil, but the soap is the preferable process, and seldom fails. Benzine is largely used by dress dyers to remove recent stains; care must be taken to keep it from fire of any kind, as its volatility is exceedingly great. It is essential that all oil or grease be removed before dyeing.

To Remove Iron Stains.—Take a little hydrochloric acid in a basin or saucer, and make it slightly warm, then dip the iron stain into the acid for about one minute, which will dissolve the oxide of iron; the cloth must be well washed from this, first in water, then in a little soda and water, so as to remove all trace of acid. A little oxalic acid may be used instead of hydrochloric, but more time is required, and with old fixed spots it is not so effective. The same precautions are necessary in washing out the acid, as oxalic acid dried in the cloth injures it.

To Remove Mildew from Cotton.—Proceed with the stains by rubbing in soap or steeping in a little soda, washing, and then steeping in bleaching liquor the same as in the process of bleaching, or by putting a wine-glassful of the stock liquor as prepared above in 1 pint of water, afterwards wash, and pass through a sour, and wash.

To Remove Indelible Ink Marks.—Steep the marking in a little chlorine water, or a weak solution of bleaching liquor, for about half an hour, then wash in ammonia water, which will obliterate the stain; the goods to be washed from this in clean water. Or they may also be removed by spreading the cloth with the ink mark over a basin filled with hot water, then moisten the ink mark with the tincture of iodine, and immediately after take a feather and moisten the parts stained by the iodine with a solution of hyposulphite of soda, or caustic potash or soda, until the colour is removed, then let the cloth dip into the hot water; after a while wash well and dry.

To Detect Animal and Vegetable Fibres.—In order to detect the different fibres in fabrics, they may be first gently heated with caustic soda, which will only dissolve wool and silk, while cotton or linen is left behind. If the alkaline liquid, on the addition of a few drops of acetate of lead, assumes a brown or black colour, wool is present. Another portion is then treated with a cold neutral solution of zinc chloride, by which only the silk is dissolved. Or, treat the fabric with tetrachloride of tin heated to from 130° to 150° Fahr., when the cotton and linen become black, and wool and silk remain unchanged.

To Detect Mixed Fabrics of Cotton and Wool.—Dip a piece of the suspected cloth in bleaching liquor; after a little the woollen turns yellow and the cotton white, and consequently may be easily distinguished.

To Detect Cotton in Linen.—The piece to be tested is boiled to remove all dressing, and then dried; a portion of the piece is put into common vitriol for about one minute, it is then taken out, washed in water several times, and then in a weak solution of soda or potash, and all gummy matter formed is removed by gentle rubbing; by this process the cotton is dissolved out and the linen remains, or what portion of the cotton is not dissolved becomes opaque white; the linen is transparent, and is thus easily detected. By comparing the portion of cloth immersed with a similar portion not tried, the quantity of cotton present may be easily estimated. Or, take a small piece of the cloth, boil in water and dry; then take 3 parts, by weight, of sulphuric acid, and 2 parts of crushed nitrate of potash; the dry piece of cloth is put into this for six or seven minutes, and then washed from this till there is no taste of acid; dry at a gentle heat; then put it into a mixture of ether and alcohol, which will dissolve the cotton and not the linen. If the piece be weighed before putting into the ether and alcohol, and after, the quantity of cotton in the fabric may be thus ascertained.

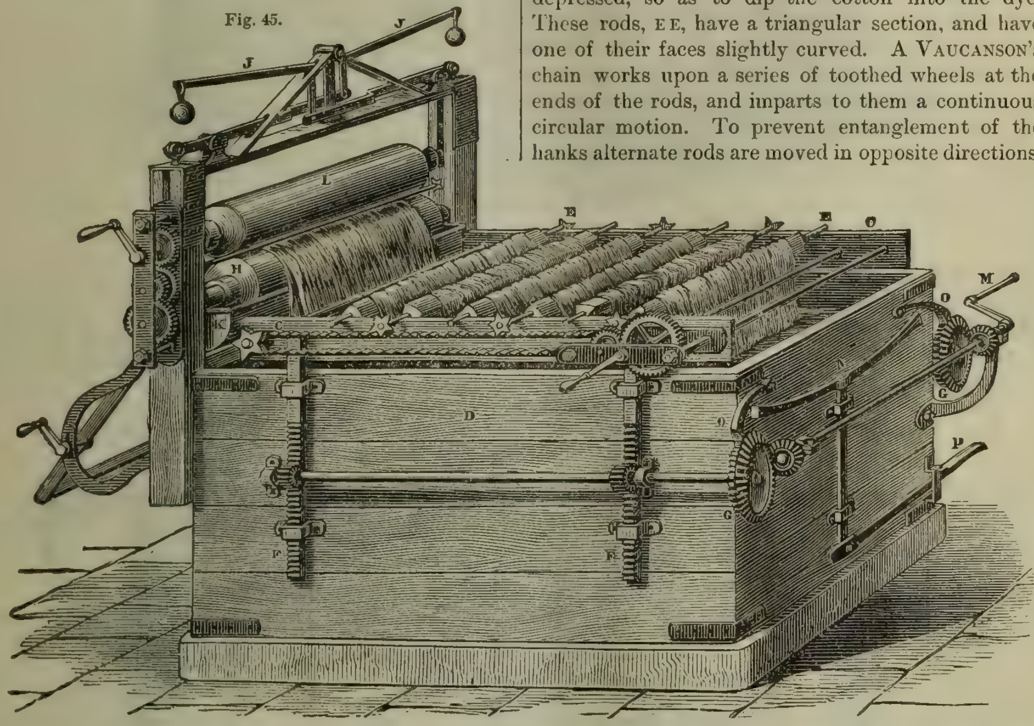
The presence of cotton in linen may also be ascertained by dipping the fabric into a solution of one part of magenta in 20 parts of spirits of wine and washing with water, which will remove the colour completely from cotton, but not completely from linen. Instead of magenta, an alcoholic solution of aurin may be used, which after washing the yarn or cloth with a concentrated solution of soda-crystals, produced a pink on linen, while cotton becomes colourless.

Cotton and Wool.—Take a small piece of the cloth and boil in caustic soda, when the wool will be dissolved and the cotton remain. If the threads have been previously counted, their relative mixture may be thus ascertained.

Cotton with Silk and Wool.—Put a piece of the cloth into chlorine water or bleaching liquor. The cotton is whitened by the liquor, and the silk and woollen become yellow. These changes will be easily distinguished by the use of a small pocket lens.

Another Method.—Take a small piece and unravel the threads and inflame them; the cotton burns away freely, with little or no black charcoal; the woollen and silk shrivel up, leave a black charcoal, and give a strong smell.

Fig. 45.



Dyeing Cotton Yarn.—Cotton is generally brought to the dye house in bundles of 5 lbs. or 10 lbs., made up of heads, each head having 10 hanks, except when the yarn is very coarse, when each head has only 6 hanks; or very fine, when each head has 20 hanks. The number of heads indicates the grist of thread, called "the number." Thus, 10 lbs. of No. 60 will have 60 heads of 10 hanks, or 30 heads of 20 hanks. These heads are made up into spindles of 18 hanks by the dyer, and through each spindle is tied a piece of stout thread or twine, termed a band; the bundle, when banded, is divided into four or six quantities, and rolled up and tied into bundles for boiling. Thus, No. 60 will give 35 spindles and 12 hanks, equal to 36, and will be rolled up into 6 sixes, or all sixes, as it is termed, or 4 nines, 10 lbs. being invariably named a bundle.

After banding, cotton is boiled in water for two or three hours until thoroughly wet. The bundles are then loosed, and each roll of yarn is put upon a wooden pin, about 3 feet in length and about 1½ inch thick, six pins or sticks forming a bundle, or four sticks, according to the division made by the bander.

An ingenious machine for dyeing skeins has been devised by M. Deshayes. A rectangular dye beck, D (Fig. 45), which may be constructed of wood, metal, or brickwork, and is heated by steam forced into it, contains the dye liquor. By means of rackwork, F F, the frame, C C, which holds the rods with the bundles of yarn, is at pleasure elevated and depressed, so as to dip the cotton into the dye. These rods, E E, have a triangular section, and have one of their faces slightly curved. A Vaucanson's chain works upon a series of toothed wheels at the ends of the rods, and imparts to them a continuous circular motion. To prevent entanglement of the hanks alternate rods are moved in opposite directions.

After a sufficient immersion the frame is raised and the hanks drained, after which they are wrung by passing them between the two cylinders, L, H, the one of which is of wood, the other of vulcanized india-rubber. The lower cylinder is provided with a vessel, K, running beneath it to catch the waste dye liquor.

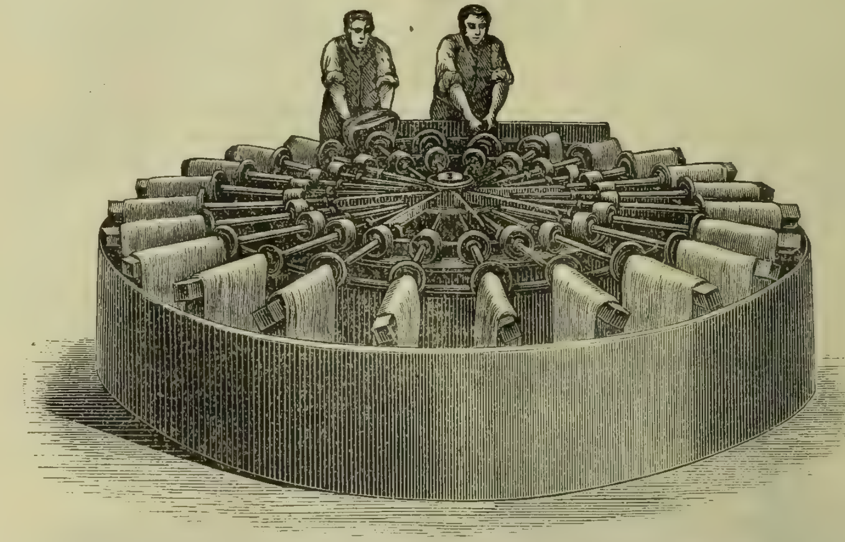
After passing through the wringing cylinders the yarn is again arranged to undergo a second dyeing. The operation is repeated until a sufficient depth of colour has been attained.

C C is the movable frame, E E are the rods which hold the yarn, F F the rackwork set in motion by the gear work, G G, moved by the handle, M. L, H, are the wringing cylinders, pressure upon which is maintained by the levers, J J.

The frame, C C, is lowered on lifting the arm, N, by treading on the lever, P, when the pauls, O O, set free the wheels, G G. The diagonal frame at the end of the dye beck is for the purpose of tilting the vessel, K, and so returning the surplus liquor into the bath.

After dyeing, the hanks are washed. A machine for this purpose, which is of almost universal use in Germany, is the circular washing machine invented by C. G. Haubold. A glance at Fig. 46 will enable the reader to understand its mode of working. Pure water flows in at the end at which the hanks are taken off, and runs away, bearing with it the surplus dye, at the place where the workman feeds the machine.

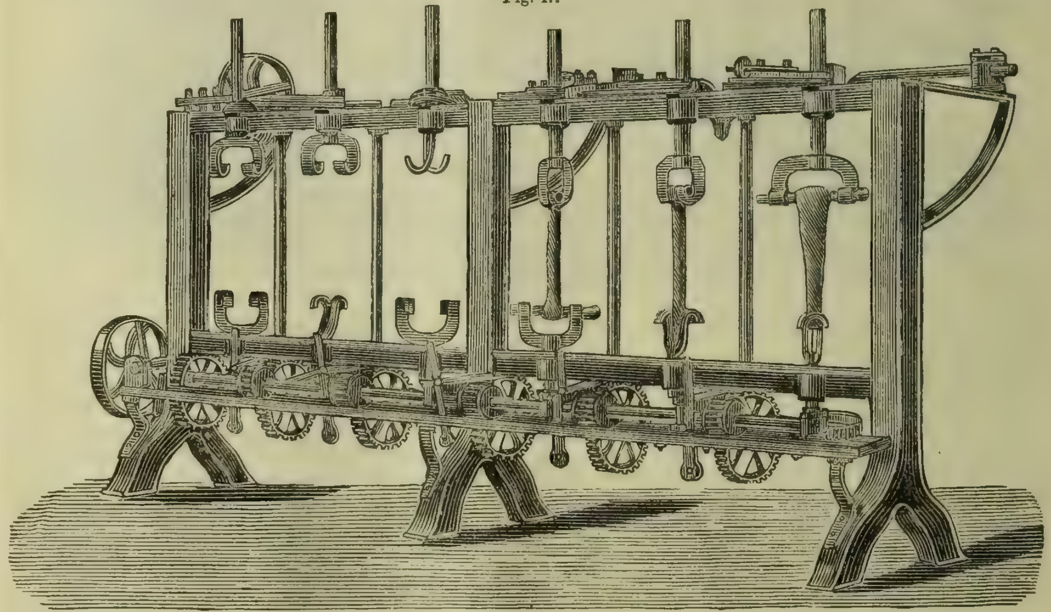
Fig. 46.



A wringing machine is shown in Fig. 47.

To dry hanks rapidly, especially in the case of wool, the hydro-extractor is much used. The particular arrangement shown in Fig. 48 is due to Burdin, who has done much to perfect this kind of machine.

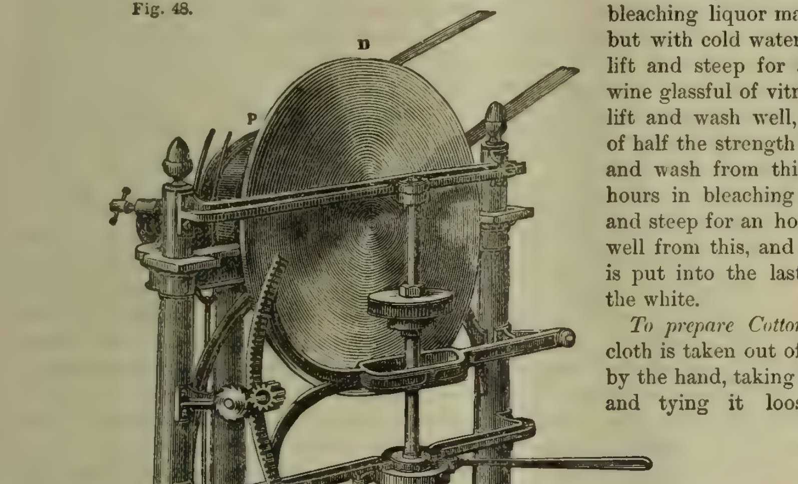
Fig. 47.



A plane circular disc, D, is set in rapid rotation by a band on the pulley, P. A friction roller, running lengthwise in a horizontal groove, bears upon the surface of the disc, and can be made to exercise a greater or less resistance by bringing it nearer to or farther from the centre. The central axle, A, carries a second friction roller, which also bears against the disc, D. By means of these two friction rollers the speed of rotation of the axle, A, can be regulated with great nicety.

The axis, A, carries a cage, into which the stuffs to be dried are put. It is then set in rapid rotation, upon which, by centrifugal force, the water is dashed through the interstices of the cage into the outer envelope, C C.

Fig. 48.



If the colour to be dyed be dark, such as brown, black, orange, deep blue, &c., the yarn is at once ready for the dyeing operation; but if for light shades, such as pink, sky-blue, &c., it must be bleached previous to being dyed, which is done thus:—A vessel sufficiently large to allow of the cotton being wrought in it freely without pressing is filled about two-thirds with boiling water; add 1 pint of bleaching liquor from the solution made up as described above for every gallon of water in the vessel, then work the yarn in this for half an hour. Into another vessel of similar size, filled two-thirds with cold water, add a wine glassful of sulphuric acid for every 2 gals. of water; stir well, and then put the yarn from the bleaching solution into this and work ten minutes, and then wash from this until all acid is removed.

This, in general, will produce a white of sufficient purity for all light shades.

But if the cotton is to be finished white, in that case the process is conducted as under:—

The yarn when banded is boiled for three hours in caustic lye, either potash or soda, made by adding 1 gill of the caustic lye, prepared as described above, for each gallon of water in the boiler; wash well from this lye, and lay the yarn to steep in a bleaching liquor made up as in last receipt, but with cold water; after four or five hours lift and steep for an hour in a sour of 1 wine glassful of vitriol to the gallon of water, lift and wash well, then boil again in a lye of half the strength of the first for two hours, and wash from this, and steep again four hours in bleaching liquor; wash from this, and steep for an hour in a clean sour; wash well from this, and dry. A little smalt blue is put into the last washing water to clear the white.

To prepare Cotton Cloth for Dyeing.—The cloth is taken out of the fold and hanked up by the hand, taking the end through the hank and tying it loosely, technically termed "kinching;" it is then steeped in old alkaline lye overnight, which loosens and removes the oil, grease, and dressing which it has obtained in weaving; it is then thoroughly washed in clean water. Where there is a dash wheel it should be used for this washing.

From these liquors often fermenting with the paste in the cloth, this process has been technically termed the "rot steep."

If the colours required upon the goods be dark, no other preparation is necessary; but if light, the cloth has to be bleached, which is done by boiling after the "rot steep" in caustic lye, of the strength of one gill of stock lye to the gallon of water, for three hours; wash out the boil, and steep in bleaching liquor for six hours, same strength as given for yarn; wash, and steep an hour in a strong sour of one wine-glassful of sulphuric acid to the gallon of water; wash well from this before drying or dyeing. If the cloth be very heavy, one operation may not be enough; in such cases proceed as at the beginning, by boiling, steeping, and souring. In bleaching cloth for dyeing, care has to be taken that it is all equally white, otherwise it will show in the colour.

If the goods be old, and have been previously dyed, and if the shade required be a deep shade, and the colour of the goods light, in that case nothing is generally required but steeping to remove any grease or starch; but if the dye upon the cloth be dark, the best method is to proceed as if they were grey goods, and subject them to a process of bleaching. The quantity of water used in the operation is simply as much as will allow the pieces or the yarn ample room to be put under the fluid easily without pressure.

Receipts.—In the following receipts, where not otherwise specified, the quantity of wares is for 10 lbs. of cotton, whether yarn or cloth. Of course any quantity may be dyed by proportioning the dyeing materials to the fabric; but when small articles are dyed—such as ribbons, gloves, handkerchiefs, or a dress—a little more of the stuff may be used without affecting the general tint of the colour, as small quantities cannot be dyed with the same economy as on the large scale. Where washing is referred to, it is always in cold water, unless hot be mentioned.

Common Black.—Steep the goods in a decoction of 3 lbs. sumach while it is hot, and let them lie over night; wring out and work for ten minutes through lime-water, then work for half an hour in a solution of 2 lbs. copperas. They may either be washed from this, or wrought again through lime-water for ten minutes—the former gives the preferable shade, but must be well affused; work them for half an hour in a warm decoction of 3 lbs. logwood, adding a half-pint of chamber lye; before entering the goods, lift and raise with 2 ozs. of copperas in solution; work ten minutes, then wash and dry.

Jet Black.—The goods are proceeded with exactly as last; but along with the logwood is added 1 lb. fustic, and finished as above.

In both these blacks, if 3 pints iron liquor be used instead of the copperas, or in part mixed with the copperas, it makes a richer shade of black, but copperas is most generally used; if mixed, use half the quantity of each.

Blue Black.—Dye the goods first a good shade of blue by the vat, and then proceed exactly as for common black; but should the blue be very deep, as is often the case, then half the quantity of the materials given above will suffice.

Spirit Brown.—The goods are dyed first a spirit yellow, and washed; they are then wrought for half an hour in a decoction of 2 lbs. lima or peach wood and 1 lb. logwood; lift up and add 3 ozs. alum in solution, and work fifteen minutes; wash and dry. By varying the proportions of logwood and lima wood, a variety of shades can be produced.

Mordant Brown.—Dye a yellow, then work for half an hour through a decoction of 2 lbs. lima wood and 8 ozs. logwood, lift and raise with 2 ozs. alum in solution; work for fifteen minutes, and wash and dry.

This method is well adapted for cloth goods, is better than the spirits, and more easily performed by the non-practical man. The spirit brown is best for yarn.

Cinnamon Brown.—Dye a dark spirit yellow, and work for twenty minutes in 3½ lbs. lima wood and half a pound logwood; then raise, by adding 2 ozs. of alum in solution; wash in cold water, and dry.

Uvanterin Brown.—Dye a spirit yellow, and then work for twenty minutes in a decoction of 1 lb. lima wood and 1 lb. fustic; lift and raise by adding half-pint red liquor; work ten minutes in this; wash in cold water, and dry.

Fawn Brown.—Take 1 part annotta liquor and 1 part boiling water; stir well, and work the goods in this for ten minutes; wring out and wash in two waters; then work for twenty minutes in a decoction of 2 lbs. fustic and 1 lb. sumach; lift and add 3 ozs. copperas in solution; stir well, and work for twenty minutes longer; wash from this in two waters; then work for twenty minutes in a decoction of 8 ozs. lima wood, 8 ozs. fustic, and 4 ozs. logwood; lift and raise with 1 oz. alum; work ten minutes; wring out, and dry.

Catechu Brown.—Work the goods at a boiling heat for two hours, or steep for several hours if the liquor is allowed to cool, in 2 lbs. catechu, wring out, and then work for half an hour in a hot solution of 6 ozs. bichromate of potassa; wash from this in hot water. If a little soap be added to the washing water, the colour is improved.

Any depth of shade of brown may be dyed by repeating the operation.

Catechu Chocolates.—Dye a brown, as last, then work fifteen minutes in a decoction of 1½ lb. logwood; lift, and add 3 ozs. alum in solution; work ten minutes longer; wash out, and dry.

By this process a great variety of browns and chocolates may be produced, both by using different quantities of logwood, and by different depths of brown before the logwood is applied.

Chocolate or French Brown.—Dye a spirit yellow, then work for half an hour in a decoction of 3 lbs. logwood; lift, and raise with half a pint of red liquor, and work ten minutes longer; wash and dry.

Another shade of deeper chocolate will be obtained by adding 1 lb. fustic with the logwood.

Catechu Fawns.—Work the goods fifteen minutes in hot water, to which has been added 2 pints of the catechu; wring from this, and work fifteen minutes in hot water, in which has been dissolved 1 oz. of bichromate of potash; wash from this, and dry.

Catechu Fawns—Another method.—Work in the solution of catechu the same as last; wring out, and then work for fifteen minutes in warm water, to which has been added 2 ozs. acetate of lead previously dissolved; wash in cold water, and dry.

Catechu Fawns—Another method.—Work for fifteen minutes in warm water, to which has been added four pints of catechu; lift, and add 2 ozs. copperas in solution, and work for other fifteen minutes; wash from this in one tub water, and finish through warm water, in which as much soap has been dissolved as will raise a lather, and dry out.

Common Red.—Put the goods into a decoction of 3 lbs. sumach as soon as possible after being made, and let them steep till the liquor is cold, say over night; wring out, and work for an hour in red spirits diluted to from 2° to 2·5° Twaddle's hydrometer, or about one gill spirits to each gallon water; wring out, and wash well, and make a decoction of 3 lbs. lima wood and 1 lb. fustic; work the goods in this for half an hour at a heat that the hand may be held in without pain, lift up and raise by adding 1 gill red spirits; return the goods, and work fifteen minutes longer; wash out, and dry.

Barwood Red.—To a decoction of 2 lbs. sumach add a wine-glassful of vitriol, and steep the goods in this decoction for at least six hours; wring out and work in spirits, diluted to 2·5° Tw., for an hour; wring out and wash, then pass through a tub of warm water; put 10 lbs. of barwood into a boiler with water, and bring it near to the boil, into which the goods are entered and wrought amongst the wood grains for about three-quarters of an hour; lift out, wash, wring, and dry. Deeper shades may be dyed by using greater quantities of stuffs in each operation.

Common Crimson.—To a decoction of 3 lbs. sumach, the goods steeped in it over night, and then spirited at 2° Tw.; wash, and work through a decoction of 3 lbs. lima wood and 1 lb. logwood for thirty minutes, then raise with a gill of red spirits; work for fifteen minutes more; wash out, and finish.

By using only lima wood without logwood, a beautiful red crimson is obtained, and by varying the proportions and quantities, a great diversity of tints will be dyed by the same proportion of sumach and spirits.

Light Straw.—To a tub of cold water add 4 ozs. of acetate of lead, previously dissolved, work the goods through this for fifteen minutes, and wring out; into another tub of water add 2 ozs. of bichromate of potash; work the goods through this ten minutes, wring out, and pass again through the lead solution for ten minutes; wash, and dry.

Leghorn.—Proceed and finish exactly as last, but along with the chrome add a half-pint annotta liquor.

Different depths and tints may be obtained by using more or less of these stuffs, without varying the mode of working.

Annotta Orange.—Heat the annotta solution to working heat—about 140° Fahr.; work the goods in this for twenty minutes; wring tightly out, in order not to lose much stuff; wash in a couple of waters, and dry.

If this colour is passed through water made to taste sour by an acid, a very red orange, bordering on scarlet, is produced; but the hue is very fugitive.

Logwood Blue.—Dye first a light-blue with the vat, then lay in a hot decoction of 2 lbs. sumach for several hours, and keep working for fifteen minutes through water, to which has been added 1 pint acetate of alumina (red liquor) and 1 pint acetate of iron (iron liquor); wash from this in two tubfuls of hot water, then work twenty minutes in a decoction of 2 lbs. logwood; lift, and raise with half a pint of red liquor; work ten minutes longer; wash, and dry.

Fustic Green on Yarn.—Dye a vat blue, wash and wring, and then pass through the acetate of alumina at 6° Tw.; wash through a tub of hot water, and then work for twenty minutes in a decoction of 4 lbs. fustic; lift and raise with 2 ozs. alum in solution, work fifteen minutes, wash, and dry.

Bark Green on Cloth.—The goods after being cleaned, not bleached, are wrought for ten minutes in red liquor at 7° Tw., wrung out, and passed through a tub of hot water, and then wrought for half an hour in a decoction of 3 lbs. bark, lifted, and raised with half a pint red liquor, and wrought ten minutes longer, then lifted and drained. Into a tub of cold water add 5 gallons of "chemic"—neutralized sulphate of indigo; work the yellow in this for twenty minutes, wring out, and dry. Of course any depth of shade may be made in this way by varying the quantity of stuff used.

Fustic Green on Cloth.—Work the goods in acetate of aluminium at 6° Tw., and dry in a stove or hot chamber; then wet out in hot water, and work for twenty minutes through a decoction of 3 lbs. fustic; lift, and raise with 2 ozs. alum in solution; work fifteen minutes; wring out, and then work in the "chemic" neutralized sulphate of indigo; wring out, and dry.

Green with Prussian Blue.—Dye a good Prussian blue, same way as sky, according to the depth of green required; and then work ten minutes in acetate of alumina at 6° Tw.; wash in a tubful of warm water, and work for half an hour in a decoction of 3 lbs. fustic; lift, and raise with 2 ozs. of alum in solution; work ten minutes longer; wash, and dry.

Bark may be substituted for fustic in this green. If so, the bark should not be wrought very warm; and thus a finer tint is obtainable.

Sage Green.—Dye a Prussian blue, same as sky, and work ten minutes in a solution of 2 lbs. alum; wring out, and work fifteen minutes in a decoction of 1 lb. fustic; lift, and add a pint of the alum solution formerly used; work ten minutes, and then wash and dry.

Olive or Bottle Green.—Dye a good shade of Prussian blue, then mordant by working ten minutes in acetate of alumina at 7° Tw.; wring out, and wash in hot water; work for half an hour in a decoction of 3 lbs. of fustic and 1 lb. of sumach; then add half a pint iron liquor, and work fifteen minutes; then wash in one tub water having 2 ozs. alum dissolved in it, and dry.

Olive or Bottle Green—Another method.—Work the goods in red liquor at 7° Tw., wash in warm water, and work half an hour in a decoction of 3 lbs. bark and 1 lb. sumach; lift, and add half a pint iron liquor, work fifteen minutes; wring out, and then work fifteen minutes in the "chemic;" wring out of this and dry.

Olive Green.—Dye a Prussian blue, then work for ten minutes in red liquor at 6° Tw.; wash in hot water, and work in a decoction of 3 lbs. bark and 1 lb. logwood; lift, and raise with half a pint of red liquor, and work ten minutes; wash from this, and dry.

A great variety of shades of green may be obtained by varying the proportions of bark and logwood. Fustic may also be used instead of bark.

If the goods be yarn, a light vat blue may be dyed instead of the Prussian blue, and proceeded with afterwards in the same manner as above.

Puce or Lilac.—Work for an hour in red spirits made down to 2° Tw.; wring out, and wash, then work half an hour in a decoction of 3 lbs. of logwood at working temperature, about 140° Fahr.; lift up, and add 1 gill red spirits, work for twenty minutes; wash from this, and dry. Half a pint of red liquor, or 2 ozs. alum, may be added to the logwood as raising, instead of red spirits.

Another Method.—Work the goods for fifteen minutes in red liquor at 7° Tw.; wring out, and wash in one tub warm water, then work for half an hour in a decoction of 2 lbs. of logwood at working heat; lift, and raise with half a pint red liquor, or 2 ozs. alum; work ten minutes in this, and wash in a tub of lukewarm water; wring out and dry.

Light Purple or Adelaide.—The goods are laid in a decoction of 2 lbs. sumach, wrung out, and wrought half an hour through the "spirit plum;" wring out and wash in clean cold water till no taste of acid is felt on the goods, and dry.

When working with the "spirit plum," it is best to take the plum liquor into a tub or separate vessel, and work the goods in this, returning the liquor afterwards to the plum tub.

Another Method.—The goods are laid in 2 lbs. sumach, wrung out, and wrought for twenty minutes in red spirits at 2° Tw.; wash well from this, then work in the spirit plum in the same manner as last; wash out till no taste of the acid is on the goods, and dry.

Purple.—Steep in 2 lbs. of sumach till cool; work in red spirits at 2° Tw. for an hour, and wash in cold water; then work for half an hour in decoction of 3 lbs. of logwood at working heat; then lift, and add 1 gill of red spirits, and work for ten minutes more; wash in cold water, and dry.

A variety of purple shades may be dyed by this process, by slightly varying the proportions of the stuffs. If a browner tint is required, give a little more sumach; if a bluer tint, less sumach, and increase the logwood, and raise with half a pint red liquor, or 2 ozs. alum, instead of red spirits.

Lavender or Peach.—Work the goods for twenty minutes through the spirit plum, wring out, and wash in clean cold water till no taste of acid is perceived, and dry.

Logwood Lilac or Puce.—Dye the goods a good shade of Prussian blue, then work for fifteen minutes in a decoction of 1 lb. of logwood at working temperature; lift up, and add 4 ozs. alum; work ten minutes, and then wash in cold water, and dry.

Another Method.—Dye a sky blue, then in a tub of warm water add 1 gal. alum plum, and work in this fifteen minutes; wring out, and dry.

Safflower Lavender.—Dye the goods a sky-blue, then dye a safflower pink on the top of the blue, with 1 lb. safflower; but in dyeing the pink, the sulphuric acid must be added to the safflower liquor previous to the blue being entered into it, otherwise the alkali of the safflower will destroy the blue.

It need hardly be added, that different depths of colour and different hues will be obtained by varying the shade of blue and the quantity of safflower. Deep blue with a little safflower give a lilac, or puce; while a light blue, with 4 lbs. of safflower, will give a peach colour.

Safflower Lavender—Another Method.—Dye a pink with 2 lbs. of safflower, then proceed and dye a sky blue over this, and finish exactly as described for sky blue.

Of course the remarks made on last receipt, in reference to different shades, apply equally to this method; but more safflower is required by this method than the other.

Common Drab.—Work the goods for fifteen minutes in a decoction of half a pound sumach; lift, and add 1 oz. copperas in solution and work for fifteen minutes; wash out in a tub of cold water, then work for fifteen minutes in a decoction of 4 ozs. fustic, 2 ozs. lima wood, and 1 oz. logwood; lift, and raise with 1 oz. alum in solution; work ten minutes longer, wring out, and dry.

A great variety of shades can be produced by this means, varying the proportion of the lima wood, fustic, and logwood; and different depths, by varying the quantities of sumach and copperas.

Olive Drab.—Work fifteen minutes in half a pound sumach, then add 1 oz. copperas, and work in this for fifteen minutes; wash in one tub water, and work in half a pound fustic for twenty minutes, and raise with 1 oz. alum; work ten minutes, and dry out.

Drab.—To a tub of hot water add 1 pint of annotta, which gives a light salmon colour, then proceed with this exactly as last for olive drab; or, by varying the quantities in last operations, a great variety of drabs may be dyed.

Stone Colour.—Work the goods twenty minutes in a decoction of 1 lb. sumach; lift and add 1 oz. copperas in solution; work fifteen minutes, and wash in one tub cold water; then work ten minutes in warm water, to which half a pint alum plum has been added; wring, and dry.

This gives a reddish tint; but if this tint be not required, the alum plum may be dispensed with, using half an ounce alum in the water.

Catechu Stone Drab.—Work the goods for fifteen minutes in 2 pints catechu in hot water; lift, and add 2 ozs. copperas in solution; work for fifteen minutes, and wash in one tub of water. Into another tub of warm water add a decoction of 2 ozs. logwood; work the goods in this for ten minutes; lift, and raise with half an ounce alum; work ten minutes longer, wring out, and dry.

Catechu Drab.—Work the goods for fifteen minutes in hot water, to which has been added 1 pint catechu, then lift, and add 1 oz. copperas; work ten minutes, and wash out and dry.

Fast Black to bear milling (100 lbs.)—Boil in water 8 lbs. of solid extract of logwood and 1¾ lb. extract of bark, and boil the yarn in this one and a half to two hours, and longer if needful. Enter in a cold beck of 1 lb. chromate of potash and 12½ ozs. of blue vitriol, and give it six or seven turns. Then return to the extract beck, in which 2½ lbs. soda have been dissolved meantime; give five turns, let stand a while, give two more turns, and lift. This beck is used at a hand heat. Then add 2 lbs. copperas; re-enter, and give five more turns.

Sumach Black (50 kilos).—Prepare with 10 kilos. of sumach over night at a boil; enter in a fresh beck of 7 kilos. copperas and 1 kilo. precipitated chalk; work cold for an hour, take out, and air. Make up a fresh beck with 3 kilos. quicklime, and work till it appears an even brown all over; rinse well, and dye in a fresh beck at 75° C. with 25 kilos. of Domingo logwood and 5 kilos. bark; sadden, lastly, in the same beck with 1 kilo. copperas.

Black for Yarns, not to Smear (5 kilos.).—Boil 1 kilo. sumach, and steep the goods in the boiling liquid for six hours; lift, steep thirty minutes in black liquor; lift, and return to the sumach beck, give five turns, and re-enter in the black liquor; expose to air for two hours. Dissolve 170 grms. chromate of potash, and make up a cold beck; work in this for ten minutes, and rinse. Extract 1 kilo. logwood and a quarter kilo. bark in boiling water; make up a beck at 62° C.; work in this for fifteen minutes; lift, rinse, and dry.

Fine Black on a Vat Ground (12½ kilos.).—Give a blue in the vat, take out, and treat with 3 kilos. sumach; take through nitrate of iron, and then through weak lime-water without rinsing; and, lastly, dye in logwood.

Blue Black for Cotton Velvets (10 lbs.).—Take through a beck of soda at a boil, which if cold would mark 2° B.; rinse, and steep over night in the decoction of 2 lbs. myrobalans, lift, drain, and work for fifteen minutes in iron liquor at 5° B. Work then for fifteen minutes in a cold beck of 1 lb. alum and 1 lb. blue vitriol; rinse, and dye at 50° C. with 2 lbs. logwood and half a lb. bark for fifteen to thirty minutes.

To soften the goods take them through an emulsion of half a lb. olive oil and 2½ ozs. potash, and dry.

Light Blue for Cotton Wool (50 kilos.).—Prepare at a boil with 10 kilos. sumach, lift, whiz, and work for thirty minutes in a beck with a quarter kilo. Nicholson blue at 70° C.; take out, dissolve in the same beck 5 kilos. of alum, re-enter, work at 50° C. for fifteen minutes, whiz, and dry.

Logwood Blue for Yarns (5 kilos.)—Dissolve half a kilo. solid extract of logwood in hot water, and make up a beck at 36° C.; enter, and give seven turns; lift, and expose to air for eight hours. Return to same beck, and give seven more turns, and make up a new beck with 340 grms. blue vitriol; enter in this, give seven turns; wring out, and return to the logwood beck in which half a kilo. sulphate of alumina has previously been dissolved; give seven turns, return to the blue vitriol beck, rinse well, and dry.

Vat Blue, with Catechu Ground (10 lbs.).—Boil 1 lb. catechu in water, dissolve in it 5 ozs. tin crystals, and work in this for two hours at 62° C.; wring out, and enter in a beck of 2½ ozs. chromate of potash at 25° C.; lastly, dye to shade in a common cold vat.

Dark Blue on Vat Ground for Twills and Fustians (17½ kilos.).—Boil for two hours with 1 kilo. of soda ash, wring, and rinse; give it a light blue in the copperas vat, and take through water at 50° C. acidified with 1 kilo. of sulphuric acid, and rinse. Make up a cold beck with 5 kilos. nitrate of iron and 90 grms. tin crystals, and work the goods in it for one hour, and then dye in a fresh cold beck with 5 kilos. logwood and 1½ kilo. alum. If a darker shade is required, put in the spent logwood bath the solution of 40 grms. chromate of potash, re-enter the goods, and work for half an hour.

Toning for Vat Blue Yarns (10 kilos.).—Dye in the cold vat a medium blue, if a dark shade is required, and a light blue for a medium shade. Then take through a cold beck with a half kilo. of sulphuric acid.

Enter in a fresh cold beck made up with 2½ kilos. logwood, work forty-five minutes, and transfer to another beck of half a kilo. alum. Work here for an hour, lift, add 100 grms. tin crystals, stir up well, re-enter and work for an hour, and finally pass through water.

Brown for Yarns and Pieces (12½ kilos.).—Prepare with sumach, and steep over night in a beck made up with 1¼ kilo. sulphate of alumina. Dye with 5 kilos. peachwood and 1¼ kilo. fustic, saddening finally with decoction of logwood.

Fast Red Brown (5 kilos.)—Boil 1 kilo. cutch in water, settle, and in the clear dissolve 100 grms. blue vitriol. Work the yarns at a boil, and make up a fresh beck at a boil with 130 grms. chromate of potash. Work for fifteen minutes and rinse. Boil 1½ kilo. sumach in water, work for a quarter of an hour in the liquid at 85° C., lift, and dissolve 80 grms. tin crystals in the beck. Re-enter, work for a quarter of an hour, and wring out. Make up a fresh beck of 1 kilo. peachwood and 250 grms. alum. Work in this for an hour at 36° C.

Brown (100 lbs.).—Boil 20 lbs. of catechu in water; dissolve in the solution 10 lbs. of alum; let settle; enter the yarns in the hot liquid, and after working it take out and enter in a fresh beck at 212°, made up with 4 lbs. chromate of potash. Rinse and soften with oil and soap.

Fast and Bright Brown (10 lbs.).—Boil in water 2 lbs. genuine Pegu cutch; dissolve in the liquid 3 ozs. of blue vitriol, and make up with water to 70 litres. Let settle; heat the clear liquid to a boil, enter the yarn, and steep for two hours. Lift, and enter in a fresh boiling beck of half a pound of bichrome. Give six turns, take out, and rinse in cold water.

For a finer shade make up a fresh beck at 37° C. with half a pound of alum and 1 oz. tin crystals, and raise the yarn in it, adding, if needful, a little magenta.

Chamois for Cotton Wool (25 kilos.).—Work in a cold beck with 2 kilos. nitrate of iron at 50° B., for ten minutes. Lift, whiz, loosen, work in a lukewarm beck with 2½ kilos. soda for ten minutes, take out and rinse.

Crimson for Yarns (5 kilos.).—Work in a weak sumach beck, and mordant with a quarter kilo. of sulphate of alumina. Dye with 2 kilos. of peachwood for an hour; lift, and add to the beck half a kilo. of nitro-muriate of tin; re-enter, steep four hours, wash and dry.

Fast Chrome Green for Yarns (5 kilos.).—Ground from pale to medium blue in a moderately sharp vat; sour with 250 grms. sulphuric acid, rinse, take through warm water at 62° C., enter in a cold beck of 80 grms. chromate of potash, and give a couple of turns. Lift, and add to the beck 250 grms. sulphuric acid, stir up, re-enter the yarn, and work till even. Rinse and dry.

Light Grey on Pieces (60 lbs.).—Boil 1½ lb. solid extract of logwood and half a pound of extract of bark in water. Run the pieces six to eight times through, press, and run through a fresh beck of 5 lbs. copperas. Rinse and finish with the following mixture:—45 lbs. farina. 3 lbs. wax, and 6 lbs. cocoanut oil are boiled to a stiff paste. The pieces are calendered out of this mixture and pressed.

Medium Grey (60 lbs.).—Increase the extract of logwood to 2½ lbs. and the bark extract to three quarters of a pound, and use 10 lbs. of copperas.

Dark Grey.—4 lbs. extract of logwood and 1½ lbs. bark extract, 15 lbs. copperas. Add to the finishing mixture logwood liquor and copperas enough to colour it slightly. If a yellow tone is required add more bark liquor, and for a reddish shade take some extract of sapan.

Mode Grey (5 kilos.).—The yarn, previously cleaned, is worked for two hours in the decoction of 1 kilo. sumach and 130 grms. fustic. Take out and dye in a fresh beck with 130 grms. copperas. Top in clear solution of gentiana or methyl violet.

Dark Macarat (10 lbs.).—Boil 2 lbs. catechu in water; in the solution dissolve 5 lbs. sulphate of copper, and work the goods in this at a boiling heat. Leave them over night in the liquor, take out in the morning, and pass them through a beck of half a pound of chromate of potash at a boil. Lift, and soak for 30 minutes in tin solution at 2½° B. Lift, and top with the decoction of 2 to 3 lbs. of logwood at a hand heat. Work in this for an hour, lift, add 1½ oz. tin crystals, re-enter, work, wring, and dry.

Light Olive (5 kilos.).—Boil 1½ kilo. fustic in water, make up a beck with the extract, dissolve in it half kilo. alum, enter and steep for an hour: take out and dissolve in the beck 32 grms. extract of indigo, re-enter, and work for a quarter of an hour.

Medium Olive (5 kilos.).—Extract 250 grms. sumach in boiling water, enter in the clear liquid, steep, and make up a fresh beck with 250 grms. copperas. Enter the yarn previously wrung out, work it for fifteen minutes, wring out and enter in a fresh beck acetate of alumina at 1° B., give twelve turns at 62° C., wring out, and work for half an hour in a fresh beck of 1¼ kilo. bark.

Dark Olive Reseda (5 kilos.).—Boil out half a kilo. sumach, and work for an hour in the clear liquid. Make up a fresh beck with three-quarters kilo. copperas, work for a quarter of an hour, wring out; give twelve turns in a fresh beck of red liquor at 1° B. at 62° C. Take out and work for an hour at 62° C. with 2½ kilos. bark.

Light Olive (10 lbs.).—Boil 1 lb. bark in water. In another kettle boil half a lb. turmeric, and mix the two decoctions, and dissolve in them 5 ozs. alum, and 1½ oz. extract of indigo or more, as the shade requires. Soak the yarn in this liquid at 31° C., and top with extract of Brazil wood.

Fine Orange for Yarn (5 kilos.).—I. Boil 630 grms. annotta in the solution of 320 grms. of soda crystals, and work in the hot clear liquid for half an hour. Take out and pass through a fresh beck of half a kilo. of alum at 28° C. If a redder shade is required, add solution of magenta. II. Steep the bleached yarn over night with 180 grms. of tannin. Take out and dye in a fresh beck at 62° with aniline orange (chrysaniline or phosphine).

Yellow on Yarn (5 kilos.).—Make up a mordant of red liquor at 5° B., and steep the clean yarn in it over night. Boil out 2½ kilos. of bark in water, and dye to shade in the liquid at 75° C. If a brighter shade is required, add 50 grms. tin crystals to the bark beck.

Light Rust Yellow (50 kilos.).—The yarn previously bleached is washed for fifteen minutes in a cold beck made up with 2½ kilos. nitrate of iron at 50° B. Take out and enter in a fresh cold beck made up of 2½ kilos. of soda-ash. Work for fifteen minutes, hang out to the air, and rinse. For heavier shades repeat these operations twice.

Dark Rust Yellow (50 kilos.).—Boil up 5 kilos. of yellow rosin, soap with 2 kilos. annotta and 1 kilo. young fustic. Steep the goods for thirty minutes in the boiling liquid.

Blue Black on Velvets (50 kilos.).—After cleaning lay the goods for three hours in a hot beck of 5 kilos. sumach; lift, and steep thirty minutes in cold black liquor at 3° B. Lift, spread out to air, and enter in a fresh cold beck with 70 grms. chromate of potash. Rinse, and dye in a fresh beck with 1 kilo. logwood, entering at 75° C., and raising the temperature by degrees.

New Colours on Cotton—*Alizarin Puce.*—Prepare a chrome mordant as follows:—Set up a stoneware bowl, holding 30 litres, in the open air or under a good draught, and heat gently. Put into it 3 kilos. chromate of potash in coarse powder, 4·4 litres of boiling water, 2·6 litres of nitric acid at 36° B. Stir well together, and add gradually 0·72 litres of white glycerine at 28° B., and 4·28 litres of acetic acid at 7° B. When the whole is dissolved pour into a double-bottomed copper pan, and heat to a boil with steam. Keep up the heat till the liquid in thin layers appears of a fine green. Then allow it to cool in a stoneware bowl, decant, wash the deposit of saltpetre in 0·8 litre of cold water, and add the washings to the clear liquid. The cotton is worked, or in case of pieces padded in this liquid, dried, passed through water containing $\frac{1}{10}$th of ammonia, washed, and dyed with alizarin.

Aniline Blacks.—With regard to these colours, Roscoe says*:—

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* Royal Institution Proceedings, June, 1876.

"In the year 1860 JOHN LIGHTFOOT, calico printer, of Accrington, applied to the processes of calico printing a black colouring matter which had been previously obtained in the manufacture of mauve from aniline by ROBERTS, DALE, & Co., of Manchester.

"This black colouring matter is invariably formed when either aniline or toluidine, or mixtures of these two substances, are subjected to oxidizing actions; but in spite of several researches which have recently been published on aniline black, we are as yet unacquainted with its chemical formula, nor indeed can we say that it even possesses a constant chemical composition.

"In order that a colouring matter shall be fixed or permanent, it must be fastened in some way to the fibre of the cloth. In the case of cotton this is generally effected (1) either by the precipitation of the soluble colouring matter in the fibre by means of a mordant, which forms an insoluble compound termed a lake with the colour, as in madder dyeing and steam-colour printing; or (2) by the fixation of the colour by means of albumin, as in pigment printing; or (3) by the gradual oxidation and consequent precipitation of the colouring matter in the fibre, as in indigo printing. It is to this latter class of processes that aniline black dyeing or printing belongs; for the aniline salt under the action of certain oxidizing agents passes more or less quickly from the condition of a colourless solid readily soluble in water, into that of a black amorphous insoluble powder not to be distinguished at first sight from soot. Hence if the cloth can be impregnated with the aniline and with the oxidizing agent at the same time, and if the process of oxidation can be allowed to go on in the fibre, the black will be formed, and will be permanently fixed in the fabric.

"Many oxidizing agents, such as chlorine, ozone, or electrolytic oxygen, have the power of transforming aniline into this black pigment. In most cases a high temperature is needed for this purpose. Thus, for instance, if aniline is heated with chlorate of sodium, and if then hydrochloric acid be carefully added, a deep black almost solid mass is produced. In order, however, that the process may be employed in dyeing and calico printing, it is absolutely necessary to avoid high temperatures as well as the action of strong acids, because when exposed to these the cloth invariably is rotted or becomes "tender." If a mere mixture of aniline salt and chlorate of potash be heated strongly enough, the black is formed; but the heat necessary to produce the colour is sufficient, together with the hydrochloric acid which is at the same time liberated by the decomposition, to make the cloth rotten, and therefore to render this process useless.

"It was found by LIGHTFOOT that if an addition of 4 ozs. of nitrate of copper solution was made to the pound of aniline and to the chlorate, the oxidation of the aniline went on at a lower temperature than when the copper salt was absent, and hence, when carefully worked, the black could be formed by this process without tendering the cloth. Certain technical objections to this process, however, soon arose; and in 1865 LAUTH proposed to use the insoluble copper sulphide instead of the soluble nitrate, by which means he prevented the deposition of the copper on the "rollers" and on the "doctors" which took place in LIGHTFOOT'S process. The method thus modified has been and now is extensively used for the production of black, and the chief, if not the only objection which can be urged against it is that the black thus obtained is not perfectly permanent, but is liable to become green when exposed to reducing agents, such as the sulphurous acid contained in the impure air of our towns. This is, however, a serious drawback, and one which those practically engaged in solving such problems have not been able to remove. So much so indeed is this the case, that it is generally believed that the property of aniline black to become green when exposed to sulphurous acid, and to return to the black when treated with alkalies, is an esssential property of the substance, which may be compared with the property of litmus to change colour in presence of acids and alkalies.

"That the aniline black can not only be produced in presence of copper, but also, as LIGHTFOOT showed in the year 1871, in presence of vanadium salts, and that by vanadium alone can the black be obtained of the requisite permanent character, has now been proved beyond doubt. Moreover, the quantity of the vanadium necessary in order to produce the oxidation of the aniline is about one thousand times less than that of the copper. Thus, if a piece of calico be dipped into a solution of 2·5 grains of vanadate of ammonia dissolved in 1 gallon of water and then dried, the cloth thus prepared is capable of producing an intense black if treated with the mixture of aniline salt and chlorate. In the same way if 1 gallon of colour be made containing 20 ozs. of aniline hydrochlorate, 10 ozs. of chlorate of soda, and 3 grains of vanadate of ammonia, a mixture is obtained with which no less than from 20 to 25 pieces, or from 500 to 600 yards of cloth, such as that exhibited, can be thus printed of a permanent black.

"In dyeing, also, the vanadium will be extensively used; and in the same way only mere traces of this rare metal are requisite, whereas the copper black cannot be used for dyeing. Thus, for instance, 1 gallon of colour intense enough to dye 40 lbs. of cotton yarn black is obtained by mixing 8 ozs. of aniline hydrochlorate, 4 ozs. of sodium chlorate, and 8 grs. of vanadate of ammonia. Cotton, wool, or silk dipped twice into this mixture and then aged, or allowed to oxidize, and "raised" in a solution of carbonate of soda, is dyed a deep rich and permanent blue black. The goods may also be allowed to steep in a bath of the above strength for three days, then well washed in warm water, or boiled in a weak solution of acetic acid, to remove any bronze colour found on the surface of the silk or wool. The permanent black is then formed, and the fibre found to be quite strong.

"The part played by vanadium in the formation of the black colour may be easily explained, when we remember the ease with which the metal passes from one degree of oxidation to another; thus from V_2O_5 the highest degree, to V_2O_4, and *vice versâ*. In this way it doubtless acts, as M. GUYARD has suggested, as a carrier of the oxygen of the chlorate to the aniline, being alternately reduced and reoxidized, so that an infinitely small quantity of vanadium compound will convert an infinitely large quantity of aniline salt into aniline black, reminding one of the action of nitrous fumes in the leaden chamber.

"Some time after the discovery of aniline black, ROBERT PINKNEY, of the firm of BLACKWOOD & Co., of London, discovered, independently of LIGHTFOOT, that vanadium can be most advantageously substituted for copper in the formation of aniline black; and he employed this reaction for the preparation of a permanent marking ink termed 'Jetoline,' of which many thousand of bottles have been sold. A few grains of vanadium—say from seven to twelve—are sufficient to produce, together with hydrochlorate of aniline and chlorate of soda, a gallon of marking ink.

"The subject of the use of vanadium as a valuable dyeing agent was next taken up by the Magnesium Metal Company, of Patricroft, near Manchester; and thanks to the unwearied exertions of S. MELLOR, this firm have now succeeded not only in securing a very considerable supply of the rare element which occurs in the Keuper sandstone as the new mineral Mottramite, but are now in a position to produce a vanadium black for both calico printing and dyeing which is perfectly permanent. This is the more remarkable, as up to this time no aniline black made with copper has been produced in commerce which will withstand the reducing action of sulphurous acid.

"As the result of a large number of experiments made with various qualities of commercial aniline, and by varying the strengths of solutions, proportions of aniline and sodium chlorate employed, and also by altering the temperature and the conditions of ageing, MELLOR has found (1.) that within certain limits the purer the aniline used the deeper and more permanent is the black obtained. (2.) That there is a maximum density of colour, beyond which, if larger proportions of aniline salt and chlorate are used, corresponding advantages of colour are not obtained. This maximum colour is yielded by 16 ozs. to 20 ozs. of hydrochlorate of aniline per gallon of colour. (3.) That for the formation of a permanent black, the amount of aniline salt and sodium chlorate used for 1 gallon of colour must bear a definite relation to each other, the weight of sodium chlorate being about one half that of the aniline hydrochlorate used. (4.) That the permanency of the black depends very much upon the care and skill shown in 'ageing' the cloth. If the cloth is aged in a moist atmosphere a blue-black is developed, which is very fleeting; but if aged in a dry air, and at a high temperature, a permanent black is obtained. It is also interesting to learn that for other colours also, the use of vanadium appears to be of value, as in the production of catechu browns as well as in some of the brighter aniline dyes."

Aniline Black.—The following processes are at present in use. The goods are stretched out tightly, and exposed to the spray of solutions of a salt of aniline and of the bichromate of potash. The spray is applied by means of a horizontal brush, to which a reciprocating motion is given by suitable machinery. The cotton takes at first an intense green, but becomes a full black on washing and passing through a soap beck. A mixture of equal measures of bisulphate and bimuriate of aniline gives the best results, and the bichromate solution should contain 10 per cent. of the solid salt.

Aniline Black.—MÜLLER-PACK prepares protochloride of iron by dissolving 3 parts of iron in a mixture of 10 parts muriatic acid and 10 of water, and lets the solution down to 17° Tw. In this the yarn is steeped for two hours, and is then aired for twelve hours. Meantime a solution is made of 3 parts aniline in 5 parts muriatic acid and water, and $2\frac{1}{10}$ parts of chlorate of potash are added, previously dissolved in 30 parts of water. In this mixture the yarn is steeped, and is then heated in a covered vessel gradually to from 30° to 50° C., and is then hung out to the air. It is next taken through a beck of bichromate of potash. If this black is passed through weak sulphuric acid and then through water and weak caustic soda it takes a bluish tone.

Aniline Blues.—If about to dye with diphenylamine blue (the sulpho-conjugated salt of the blue being a compound of lime or baryta), work the cotton in solution of tannin at 3 per cent.; pass through the solution of the blue, dye in water, and dry.

If alkaline blues are employed, the sulpho-conjugated salts of which are soda or ammonia compounds, take for 10 kilos. of cotton a solution of tannin containing 3 per cent. of the weight of the cotton; boil for fifteen minutes, wring, and pass into a beck of $1\frac{1}{2}$ kilo. alum, a quarter tartar emetic, three quarters soda crystals, and a quarter tartaric acid. These wares are all dissolved separately, and the solution of the blue is added last. Heat to 65° to 70° C., enter the cotton, and dye, letting the temperature sink by degrees. The beck may be used continuously, adding more mordant as it becomes spent. It is best to dye first heavy shades in the beck, then mediums, and then light shades.

For saffranin and the aniline greens the goods are passed first into a beck of perchloride of tin at 2° B., wrung, passed into a tannin beck, wrung again, and entered in the dye beck.

Cotton may also be mordanted in a solution of nitrate of urea (2 grms. per litre of water), boiled, wrung, passed into a solution of biphosphate of lime (5 grms. per litre of water), wrung, and entered in the dye beck. From this manner very bright shades may be obtained with almost all the anilines.

Guernsey Blue for Yarns (10 lbs.).—Prepare with 2 lbs. sumach, and dye at 32° C. with the solution of 2 lbs. Guernsey blue; lift, add 1 lb. alum, give the yarn a few more turns, take out, and dry.

Fast Aniline Blue for Yarns (5 kilos.).—Steep for three hours in a hot beck of 250 grms. of tannin; wring, and enter in bichloride of tin at 4° B. for two hours; rinse, and let lie over night. The next day enter in a beck of half a kilo. curd soap at 75° C; work for an hour, lift, and make up the dye beck with aniline blue (not Nicholson's) and a little sulphuric acid. Heat to 50° C.; and enter, raising slowly to a boil. Dye rather darker than the pattern; wring, and pass through a beck of half a kilo. curd soap at 75° C.; rinse, and take through a beck of half a kilo. alum; dye without rinsing.

Deep Bismarck Brown on Velveteens (40 to 45 lbs.).—Run through decoction of catechu at 4° Tw. and 180° Fahr.; raise with solution of bichromate of potash at 2° Tw. and 150° Fahr.; wash off, and take through 60 gals. fustic liquor; lift, drain, and stove dry; singe, and repeat the catechu, chrome, and fustic, and stove as before. Enter in a beck of Blackley brown at 170° to 180° Fahr.; 8 to 10 ozs. of colour gives a good red shade. The fustic liquor should contain 1 lb. fustic to 3 gals. water.

Eosin Pinks and Roses (10 lbs.).—Work in a hot beck made up with 1 lb. of curd soap, and then soak in a fresh beck of 4 lbs. sugar of lead. Repeat both these processes twice or thrice, according to the shade required. Lastly, work in the colour dissolved in water.

Pomona Green.—Work in a tannin beck, or in an extract of gall-nuts or myrobalans. Lift, and run through a very dead double muriate of tin. Take through cold water, and then work in a cold solution of the colour.

Linen is steeped for twelve hours in a beck made up of tannin or decoction of galls. Next work in acetate of alumina, and then dye to shade in a beck of iodine green.

Iodine Green.—Prepare with tannin, rinse, and dye at 50° C. The colour should be dissolved at 60° C., avoiding higher temperatures.

Night Green on Velveteens (1 piece).—Boil 3 lbs. of galls in 4 gals. water. Settle, draw off the clear, mix with 20 gals. water, heat to 150° Fahr. in the jigger, and run the piece six times through. Add 1 pint of double muriate to the solution, and run the piece through again. Wash, and run it six times through a beck of 4 gals. fustic liquor and 20 gals. water. Then add 4 quarts of alum liquor, at 8° Tw., and run the piece several times through this; lift and dry. Make up a jigger with 20 gals. water and half a pound of pomona paste previously dissolved. Run through till all the colour is taken up.

Turkey Red with Artificial Alizarin.—Give one oiling less than if the goods are to be dyed with madder or garancin. The tannin bath is also dispensed with. The aluming is performed in the ordinary manner with the following mordant:—To 50 kilos. of crystallized alum take 15 kilos. of soda crystals and mix their solutions in water, stirring well. The clear liquid is finally set at 5° B. The yarns are steeped for one day in this liquid and are then very carefully washed and wrung out, and are ready for the dye beck. This is made up of alizarin and tannin, half a kilo. of the latter to every 50 kilos. of cotton. If the water contains no lime, 100 grms. of chalk are added for every 50 kilos. of cotton. Begin to dye with a perfectly cold beck, raise the temperature gradually for two hours to the boiling point, and finally boil for one hour. The dyed yarn, without any clearing, is at once bloomed with curd soap and annotta. Treatment with tin crystals is only needed for rose shades.

Saffranin Ponceau and Scarlet (5 kilos.).—Prepare a boiling hot beck with half a kilo. turmeric, and work the cotton in it for an hour. Lift, drain, and take through a beck with half a kilo. sulphuric acid. Work for three hours at a boil with 1 kilo. sumach, wring and dye in a fresh beck at a hand-heat, with a clear solution of saffranin.

Saffranin Pinks and Roses.—Wash well with soap and work for two hours in a cold solution of sugar of lead at from 5° to 6° Tw. Wring out, and work in a strong soap beck at 60° C. Rinse, and dye in the solution of saffranin in water at 65° C.

Saffranin Rose for Yarns (5 kilos.).—Mordant with 1 kilo. sumach, and dye in a clear solution of saffranin. If a more blue shade is desired add 50 to 76 grms. of tin crystals to the sumach beck.

Croissart and Bretonnière's Patent Colours.—When using these colours for grey, silver grey, and brown, it is almost impossible to get the shades uneven. It seems further as if the fibre becomes animalized, and forms a ground upon which aniline grey or other aniline colours take readily.

Silver Grey (20 kilos.).—Two becks are required, both at a boil. *Beck* I.—Patent colour No. 1 of the Göttingen works, more or less according to shade. II. *Fixing Beck.*—1 litre of red liquor at 10° B. Enter in I., then in II.; lift, add aniline grey, and dye to shade.

Grey (25 kilos.).—2½ kilos. of patent colour No. 1. Fixing beck: 2 kilos. copperas and 1 kilo. blue vitriol.

The flat is preserved, and strengthened with 100 grms. of patent colour No. 1 for the next lot.

Brown (25 kilos.).—3 kilos. of patent colour No. 18. Let steep over night in the hot liquid. Lift, and take through the clear solution that remains when a quarter of a kilo. of chromate of potash and half a kilo. of copperas are mixed and allowed to settle.

Sky blue with Lo-kao.—Dissolve in a bath of hyposulphite of soda. A fast light blue is obtained, not affected by light. In an ammoniacal solution it gives a violet on cotton without a mordant.

Linen and Jute.—*Bleaching Linen* (100 lbs.).—Make up a boiling solution of 25 lbs. quicklime and 12 lbs. soda ash. Let cool, enter the yarn, and steep in the cold for twelve hours. Take out, rinse, and pass through weak sulphuric acid. Rinse again; stir up 8 lbs. good chloride of lime in water, let settle, and enter the yarn and steep till perfectly white. Lift, rinse, and pass through weak muriatic acid. Dissolve 2 lbs. curd soap in boiling water, add as much ultramarine as may be required for a blue tint; stir well up, enter the bleached yarn, take out, and dry.

Black Linen (40 lbs.).—The goods are made perfectly clear and steeped for an hour in the solution of 4 lbs. solid extract of logwood. Squeeze well, and take eight times through a cold beck of 7½ ozs. bichromate and 12 ozs. blue vitriol. Squeeze, and dissolve in the first bath 1 lb. soda ash. Heat to 75° C., squeeze again, and dissolve in the bath 1 lb. copperas. Work for half an hour, and rinse. To hinder the goods from smearing, take through water in which a little gum has been dissolved.

Greenish Mode Grey Linen (10 kilos.).—Dissolve one-half kilo. soda-ash in water, and make up so that the linen can lie in the liquid, and boil for an hour. Wash, and take through a beck of one-half kilo. sulphuric acid, and wash again. 1 kilo. chloride of lime is stirred up to a cream with water, let settle, and the linen is steeped in the clear liquor for six hours, with occasional turning. Lift, and take through cold water to which 1 kilo. muriatic acid has been added. This preparation is needed for all light colours. Boil out one quarter kilo. sumach, and 1 kilo. bark. Work in the clear liquor for one hour, wring, and put in a fresh beck of one quarter kilo. copperas. Work for fifteen minutes, and pass through water. Top in a beck of 1 kilo. alum at 50° C., and add by degrees very small doses of bark liquor and extract of indigo, till the shade is obtained. Rinse, and dry.

Magenta on Linen Yarn.—Prepare with 5 lbs. olive oil, 1 lb. sulphuric acid, 10 lbs. water, and 10 lbs. methylated spirit at about 60° Fahr., and let steep for three hours, wring, and drain. Then add one-quarter lb. vitriol, and pass the yarn five times through the liquid, wring, and enter in a magenta beck at 140° Fahr.

Red, Fast Sanders, on Linen Yarn (100 lbs.).—Ground slightly with annotta; mordant by steeping over night in perchloride of tin at 8° B. Rinse, and wring, and enter in a beck made up with 5 lbs. of sanders, and work at a boil for twenty minutes. Take through sulphuric acid at ½° BEAUMÉ, wring, and rinse.

Brown on Jute (5 kilos.).—Boil out 1 kilo. catechu in water, and dissolve in the clear liquid 100 grms. of blue vitriol. Steep the jute in this at a boil for two or three hours. Lift, and make up a beck at a boil with one quarter kilo. chromate of potash; take the jute through this, and then through water. Top in a fresh beck with 5 grms. Bismarck brown (aniline), 130 grms. alum, and one half kilo. logwood.

Cherry Brown (5 kilos).—Boil 1 kilo. of sumach, and work for an hour in the clear boiling liquid. Lift, and dissolve in the beck 50 grms. tin crystals; enter again, and work for fifteen minutes. Lift, and make up a fresh beck with 1 kilo. logwood, 80 grms. magenta, and 400 grms. alum. Work for an hour in the cold liquid, lift, add to the same beck 80 grms. chromate of potash, re-enter, work for thirty minutes, and rinse.

Light Brown on Jute (25 lbs.).—Dye hot with 2½ lbs. catechu and 4 ozs. blue vitriol. Lift, and enter into a hot beck of from 4 to 6 ozs. bichrome, according to shade, and give two or three turns.

For a medium brown, to the same quantity of yarn use 5 lbs. catechu, 8 ozs. of blue stone, and 12 ozs. bichrome.

Dark Brown on Jute (25 lbs.).—Work hot with 5 lbs. catechu, 6 ozs. alum, 8 ozs. blue vitriol, and 4 lbs. logwood. Lift, and give two or three turns in a beck of from 8 to 12 ozs. bichrome. If not dark enough, enter in a logwood beck with one quarter lb. alum. If a redder tone is required top with magenta in a separate beck.

Aniline Green on Jute (25 lbs.).—Prepare with 5 lbs. myrobalans; then work in a red liquor made from 4 lbs. alum and 22½ lbs. sugar of lead, using the clear only; wring, and dye in the solution of aniline green.

Light Green on Jute (5 kilos.).—Boil out one quarter kilo. sumach, and steep for three hours in the clear boiling liquid. Lift, and make up a cold beck with methyl green. Enter the jute, and work till the colour is even. For yellower shades add picric acid.

Prussiate Green on Jute (5 kilos.).—Make up a boiling beck with 1 kilo. extract of bark, and as much alum. Steep for an hour, lift, and prepare the two following becks:—I. 250 grms. nitrate of iron; 40 grms. tin crystals. II. 136 grms. yellow prussiate. Work in I., then give five turns in II., lift, and add to II. 250 grms. sulphuric acid, and give five turns. Work for thirty minutes in acetate of alumina at 2° B., and dye up in a fresh beck of extract of indigo and a little bark.

Aniline Green for Jute Yarn (45 lbs.).—Work for an hour in the hot decoction of 5 lbs. myrobalans; mordant with 4 lbs. alum and 2½ lbs. acetate of lead, using the clear only. Let it steep for two hours, and then dye with the solution of aniline green.

Orange on Jute.—Mordant the yarns with basic acetate of lead; wring, enter in lime-water, give six turns, and wring again. Enter in a bichrome beck of 1½ lb. to 2 lbs., with 1½ lb. sulphuric acid. Wring, and enter in boiling lime water; give three turns, lift, and wash.

Red on Jute (5 kilos.).—Steep for an hour in the decoction of 250 grms. tannin at 90° C. Lift, and make up a beck with 80 grms. aniline orange at 60° C., and dye. Lift, add the clear solution of 40 grms. saffranin to the beck, re-enter, and dye to shade. (An expensive colour.)

Yellow on Jute (5 kilos.).—Bleach, and enter in a cold beck of 80 grms. sugar of lead, and work for fifteen minutes. Lift, and work for the same time in a cold beck of 80 grms. chromate, and rinse. If a redder tone is required, work lastly in weak magenta.

PREPARING AND DYEING OF SILK.—Silk is banded in the same manner as cotton, using no particular number of hanks, but in quantities convenient for making up into skeins when finished. After banding, it is carefully tied up and put into fine canvas bags, and seethed in these in a strong solution of soap for three or four hours, until all the gum is boiled off. If the silk be yellow gum, it is put upon sticks like the cotton, and wrought in a solution of soft soap, at a temperature just approaching the point of ebullition, for about an hour, when it is tied up as the white gum silk, and put into bags and boiled till all the gum is removed; when boiled, it is washed from the soap, and "sticked" for dyeing, putting six or eight heads of silk on each stick. This is all that new silk requires before dyeing.

The first operation with goods to be re-dyed is steeping in a strong saponaceous solution at nearly 212° Fahr. for a few hours, in order to remove stains of oil or grease; they are afterwards washed in water, and if the colour remaining upon them after this operation be light and equal, and the tint wanted be dark, then no more is required; but if unequal, they should be put into a sour for fifteen minutes, then washed out, and proceeded with for the colour required.

The quantities of dyestuffs given in the receipts that follow are for dyeing 5 lbs. weight of silk. In cases where the silk is very hard spun, as in some ribbons and dresses, a little more dyestuff may be used than the quantities given, and also a little more time. Some kinds of goods will be bulkier than others of the same weight; in such cases, less or more water may be used accordingly. The quantity of water must always be sufficient to allow the goods to be quite loose when immersed under the surface.

When goods are washed from the dye, it is always in cold water, except otherwise mentioned in the prescription.

Black.—Work for an hour in a solution of 8 ozs. of copperas, and wash well out in cold water; then work an hour in a decoction of 4 lbs. of logwood, adding to it half a pint of urine; lift out, and add to the logwood liquor 2 ozs. copperas in solution; work fifteen minutes, wash, and dry.

This will give a good black, not very deep. If a deep black is required, add to the copperas solution 2 ozs., by measure, nitrate of iron; indeed, for re-dyes, it will be better to add this at all times. If a blue shade is desired, instead of adding urine dissolve a little white soap in the logwood liquor, and add no copperas.

Full Deep Black.—Work an hour in 1 lb. copperas and 2 ozs. nitrate of iron; wash, and work for an hour in a decoction of 5 lbs. logwood and 1 lb. fustic; lift, and add 2 ozs. copperas, work ten minutes; wash, and finish.

If the colour is not deep enough, add a little more logwood before raising with the copperas.

French Black.—Work an hour in 1 lb. copperas and 4 ozs. alum; wash well, and then work an hour in a decoction of 4 lbs. logwood, in which a little white soap has been added; wash out, and finish.

Blue Black by Prussiate.—Dye a deep Prussian blue as already described, and work from the prussiate for half an hour in 8 ozs. copperas; wash well from this in cold water, and then work for half an hour in a decoction of 2 lbs. logwood, using neither urine nor soap in it; lift, and add a little of the copperas solution with which the goods were mordanted; work other ten minutes, then wash and dry.

Deep Hat Black.—Work the silk fifteen minutes in a decoction of 2 lbs. fustic and 1 lb. bark; lift, and add in solution 6 ozs. acetate of copper and 6 ozs. copperas; work for another fifteen minutes, and then sink the whole under the surface, and let it steep for several hours, say over night; lift, and wash from this, then make a decoction of 5 lbs. logwood; dissolve in it as much white soap as will make a lather, and work in this for an hour; wash out, and dry.

Brown.—Dye an orange with annotta (see *Orange*); then work for fifteen minutes in a solution of 8 ozs. copperas; wash from this in two waters, and then work half an hour in a decoction of 3 lbs. fustic, 8 ozs. logwood, and 1 pint archil liquor; lift, and add half a pint alum solution; work ten minutes, wash, and dry.

One pound of Brazil or peach wood may be substituted for the archil liquor, with nearly the same results. A variety of this shade of brown may be dyed by varying the quantity of each stuff.

Brown.—Dye an orange by annotta (see *Orange*); and then work for twenty minutes in a decoction of 3 lbs. fustic, 8 ozs. sumach, 8 ozs. peachwood; lift up, and add 3 ozs. of copperas in solution; work another fifteen minutes, wash out in two waters, using half a pint of alum solution in the last water.

If the particular tint required is not obtained by the above proportions, it may be given in the water with the alum, using it a little warm. If yellowness is required, add fustic. If redness is wanted, add peachwood. If depth or blueness, add logwood.

A great many particular hues of brown may be dyed by this method; as, for instance, by using only fustic and sumach in the second operation, a California brown is obtained, &c., as just referred to, so that any intelligent workman will easily regulate his colours and tints.

Red Browns.—Dye a deep orange by annotta (see *Orange*); then work for fifteen minutes through the spirit plum liquor (which see) wash well, and dry.

Particular tints may be given by adding either logwood, peachwood, or fustic in the last washings, as described in last receipt.

Another Method.—Steep the silk in an alum solution of 8 ozs. to the gallon for an hour, and wash out in warm water; then work half an hour in a decoction of 1½ lb. fustic, 1½ lb. peachwood, 8 ozs. logwood; lift, and add 1 pint of the alum solution, work ten minutes; wash, and dry.

Chocolate Brown.—Steep the silk for an hour in alum, 1 lb. to the gallon of water; wash once in warm water, and then work for half an hour in a decoction of 3 lbs. peachwood and 1 lb. logwood; lift, and add 1 pint of the alum solution; work in this for fifteen minutes; wash out, and dry.

Deeper shades of chocolate are obtained by using a smaller quantity of peachwood and more logwood, in equal proportions. A little fustic, say 4 ozs., may be added, which will give a still deeper hue if required.

Bronze Brown.—Work for half an hour in a decoction of 8 ozs. fustic, to which 4 ozs., by measure, of archil liquor has been added; then lift, and add 2 ozs. of the solution of copperas; work fifteen minutes, wash in cold water, and finish.

Pink.—Prepare the safflower as already described; then take a quantity of solution equal to 1 lb. of safflower originally used; add to this solution 1 oz., by measure, of sulphuric acid; enter the silk, and work for half an hour; then wash in a vessel with warm water in which about 1 oz. cream of tartar has been dissolved; wring out, and finish. Lighter or darker shades may be dyed by using less or more safflower; when more is used, a little more time will be required.

If safflower extract be used, which is simply the red colouring matter precipitated by an acid, add about a pint of the extract to warm water, with half a wine-glassful of sulphuric acid; stir well; work the goods in this, and proceed as above.

Cochineal Crimson.—To every gallon of water used add about 2 ozs., by measure, bichloride of tin (double muriate); allow any sediment to settle, and take the clear solution, and apply heat; when warm, work the goods in it for an hour or more.

Boil in a bag 2 lbs. of cochineal, by suspending it on the surface of the water for half an hour; add this to the proper quantity of water for working the goods, the whole being at hand-heat; wring the silk from the spirits, and work it in this cochineal solution for half an hour, when it is let steep for several hours, keeping well under the liquor; wash well out of this in cold water. If the shade is not blue enough, a little cochineal dissolved in ammonia may be added to the water; and after working in this for ten minutes, wring out and dry.

Common Red.—Make a decoction of 2 lbs. peachwood and 1 lb. fustic, work the goods in this for fifteen minutes; lift up, and add 4 ozs., by measure, red spirits; work again fifteen minutes; wash in cold water, and finish.

A variety of tints may be dyed in this way by altering the proportions; and by adding a little logwood, clarets and such shades can be produced; but these common colours do not stand the air well.

Cochineal Pink.—This hue is dyed in the same manner as the crimson, only using much less cochineal; about half a pound will make a good colour. Different shades of pink, rose, and crimson can be dyed by this method, by varying the quantities of stuff used.

Cochineal Scarlet.—Dye a deep orange by annotta; and proceed in the same way as for crimson, passing through the spirits, and then cochineal, as stated above.

Different shades of common reds and crimsons may be dyed by mixing up the following:—Make a strong decoction of lima or Brazil wood by boiling, using at the rate of 1 lb. wood to the gallon of water. When the boiling has ceased and the wood settled to the bottom, decant the clear and allow it to cool for twenty-four hours, then decant again from any sediment that may have collected, and to every gallon of liquor add half a pint plum spirits, stir well, and let stand for several hours, when it is fit for use.

Common Crimson.—Into a copper or stoneware vessel put some of the above liquor, work the goods in it for half an hour; then wash out in cold water until no taste of spirits is perceptible in the cloth; wring, and dry.

Common Scarlet.—Dye the goods an orange by annotta (see *Orange*); and then work in the peachwood preparation in the same way as dyeing common crimson; wash out, and dry.

Rubys, Maroons, &c.—Take 1 lb. of cudbear and boil for fifteen minutes in a bag; work the silk in this solution for half an hour. If the shade required be of a bluish tint, lift, and add 3 ozs., by measure, liquid ammonia; work ten minutes, and wring and dry.

If the shade required be of a red hue, lift, and add 2 ozs., measure, red spirits; work ten minutes; wash out, and dry.

If a brown hue is wanted, use along with the cudbear a decoction of 4 ozs. fustic; work in this, and raise with 2 ozs. red spirits, as above.

If a deep violet hue is desired, employ along with the cudbear a decoction of 4 ozs. logwood; work in it, and raise with 2 ozs. red spirits, as above.

Sky Blue.—To 1 pint of sulphate of indigo add two or three gallons boiling water; then put into this a piece of woollen cloth, such as an old blanket; after steeping for a day, take it out and wash in cold water.

If the sky blue required be very light, make up a vessel with warm water, about 98° Fahr., steep the blue cloth in this for a few minutes, and wring out, when as much blue will be dissolved off as will dye the silk; add an ounce of alum in solution, and work the silk in this for twenty minutes; wring out, and dry.

If the blue required be deep, then to the warm water in which the blanket is put add 1 oz. of pearl ash, and proceed as detailed; but before adding the silk a few drops of sulphuric acid may be poured in with the alum to neutralize the alkali.

If indigo extract be used, then the blanket or woollen cloth is not required, but to the requisite quantity of water add half an oz. of extract with 1 oz. of alum in solution, and work the silk as stated; less or more of the extract is used according to the depth of shade required.

Lavender.—Into as much water as will serve to work the goods in easily put 1 pint of spirit plum liquor; stir well, and work the goods in this for twenty minutes, then wash out in cold water, and dry.

Darker or lighter shades can be dyed by using less or more of the plum liquor.

If a blue tint of lavender is required, add to the plum liquor solution, before putting in the goods, two or three drops of sulphate of indigo, or extract, and proceed as stated.

Lavender—Another method.—Into a vessel with warm water as hot as the hand can bear dissolve a little white soap, enough to raise a lather; then add 1 gill archil liquor, and work the goods in this for fifteen minutes; wring out, and dry.

Boil 1 oz. of cudbear, and add the solution to the soap and water, instead of archil, which will give a lavender having a redder tint than that with the archil. If a still redder shade of lavender be required the soap may be dispensed with.

Wine Colour, Violet, Lilac, &c.—Into a copper pan or stoneware vessel put as much of the plum liquor as will work the goods in; then work in this for twenty minutes; wash out in two or three waters, or until the goods have no taste of the plum, then dry.

If a richer blue tint is required, add to the plum 1 oz., by measure, sulphate of indigo or extract. If a red tint is desired, dye the cloth first a lavender by cudbear without soap; then work through the plum liquor without indigo.

The plum liquor used for this colour is not thrown away; it is either put back into the stock tub or into another vessel kept for that purpose, when it may be used over again. If indigo has been taken it must not be put back again into the stock plum, or it will give the whole a blue shade: all such mixture should be kept separate.

French and Pearl White.—Into hot water dissolve a quantity of white soap, as much as makes a lather, and then add about half an oz., by measure, archil; work the goods in this for ten minutes, and finish out the soap.

A little cudbear may be used instead of archil, less or more according to the shade required.

Another Method.—Into a vessel of cold water add about 1 oz., by measure, of plum liquor; work the goods for ten minutes; wash out, and dry.

For these shades the goods should be perfectly white previous to dyeing.

Weld, Yellow.—Work the silk for an hour in a solution of alum, about 1 lb. to the gallon, wring out, and wash in a vessel with warm water. Boil 2 lbs. weld, strain the liquor, and work the alumed silk in this for half an hour, then add 1 pint of the alum solution to the weld bath, and return the silk; work for ten minutes longer, and wring out and dry.

This gives a rich lemon yellow; by adding more weld deeper shades are produced; or by using a little annotta amber and straw tints are obtained.

Gold and Straw.—Into warm water with white soap add 2 pints annotta liquor; work in this fifteen minutes; wash out, and then work twenty minutes through a decoction of 8 ozs. bark; lift, and add 1 oz., by measure, red spirits; work other ten minutes, wash out, and finish.

Different tints of these colours may be dyed by varying the quantity of annotta bottom and bark.

Salmon, Flesh, Nankeen, Buff, &c.—Make a solution of white soap in warm water, and to this add 1 pint of annotta liquor; work twenty minutes, wring out, and finish. If the shade is not deep enough, add a little more annotta.

If a red tint is required, such as salmon or flesh colour, the goods are washed out of the soap and finished in water, in which 2 ozs. of alum are dissolved.

Orange.—The silk is wrought for fifteen minutes in a strong solution of annotta made warm; then wash in warm water, and dry.

The annotta made up for silk should be with soft soap, instead of potash or soda, or only a very little of these alkalies should be added.

Yellow Drab.—Into a vessel with warm water add 1 pint annotta liquor; work in this for fifteen minutes, and wash; then work another quarter of an hour into a decoction of half a lb. sumach and 1 lb. fustic; lift up, and add 4 ozs. copperas in solution and 1 oz. alum; work ten minutes, and wash in cold water, and dry.

A diversity of shades of drab may be dyed in this way, by varying the proportions of the stuff, and adding with the fustic small quantities of log and peachwood.

Drab.—Work the goods for fifteen minutes in a decoction of 8 ozs. sumach, and the same of fustic; lift, and add 4 ozs. copperas; work twenty minutes, and wash out in cold water. In another vessel with warm water add half a pint archil liquor; work fifteen minutes in this, and dry out.

If a greenish tint be required, add a decoction of 4 ozs. fustic to the archil and half an oz., by measure, of "chemic." If a purple tint is sought, add instead of the chemic 1 oz. of alum in solution.

A great variety of tints may be produced by a slight alteration in some of these ingredients.

Slate or Stone Colour.—Into a decoction of 1 lb. sumach, 4 ozs. fustic, and 4 ozs. logwood, work the silk for half an hour; lift, and add a solution of 4 ozs. copperas; work other thirty minutes, wash in cold water, and finish.

A variety of tints can be produced by this method by taking different proportions of the stuffs.

Common Green.—Steep for an hour in an alum solution of 1 lb. to the gal.; wash in warm water, and work for thirty minutes in a decoction of 6 lbs. fustic; then add 2 ozs., by measure, indigo extract; work other thirty minutes; wash and finish.

Should the shade be too yellow, as the extract often varies in quality, add more extract to the fustic before finishing.

Deeper and lighter shades are dyed by this method, by using more or less of each stuff.

Another Method.—Work for forty minutes in a decoction of 4 lbs. fustic; lift, and add 1 lb. alum in solution, and 2 ozs. by measure of indigo extract; work for half an hour in this; wash out in cold water, having in it half a pint of alum solution, and finish.

Pea Green.—Steep the silk for an hour in an alum solution of 8 ozs. to the gallon of water, and then wash out in warm water; boil 4 lbs. ebony wood chips for an hour; take the clear and work the silk in it for thirty minutes; lift, and add 1 oz. indigo extract; work ten minutes; wash in cold water, having half a pint of alum solution in it, and dry.

Care has to be taken in adding the extract, lest the quantity given be too much for the shade required; it may be better to add less, and if found not enough, lift, and add more.

Bottle Green.—Dissolve 2 lbs. alum and 1 lb. copperas; work the silk in this for an hour, and wash out in warm water; then work for half an hour in a decoction of 6 lbs. fustic; lift, and add

2 ozs., by measure, indigo extract; work twenty minutes, wash out, and finish.

Another Method.—Proceed exactly as described for common green, but add 1 lb. of logwood to the 6 lbs. of fustic, and operate in every way the same.

If a deeper shade be required, a little more logwood may be added.

Olive.—Work the silk for half an hour in a solution of 1 lb. of copperas and 4 ozs. of alum; wash out in hot water, and then work half an hour in a decoction of 2 lbs. fustic and 4 ozs. of logwood; lift, and add half a pint alum solution or 2 ozs. dissolved; work ten minutes in this; wash, and dry.

If the shade looked for have more of a green hue than pattern, add a little chemic to the last water, and work ten minutes, and dry out.

Light Olive.—Dye a light Prussian blue (see *Sky blue*), then work for twenty minutes in a decoction of 2 lbs. fustic and half a pint archil liquor; lift, and raise with half a pint alum solution, or 1 oz. dissolved; work ten minutes, and finish.

New Black.—Prepare a beck of neutral sugar of lead by dissolving 20 lbs. litharge in about 5 lbs. pyroligneous acid and an equal bulk of water, till the clear liquid at 104° Fahr. marks 44° to 45° B. Prepare also some nitrate of iron by dissolving clean scrap iron in nitric acid. The silk to be dyed, after first being well boiled and washed, is worked in a nitrate of iron beck for fifteen minutes. Then lift, expose to the air, and rinse in water, when the silk takes a rusty yellow. Repeat these operations twice. Make up a logwood beck with the addition of a little bark or fustic liquor, and heat to 86° Fahr., and add a little blue vitriol, previously dissolved in water. Enter the silk, and work from twenty to thirty minutes, or till quite even, and allow it to steep for some time longer. Wash, and lay in a tub of water containing olive oil previously saponified with soda. Work for a few minutes and wring. Enter in the sugar of lead beck at 144° Fahr.; work well, and steep for some time. Lift, wring, and dry in a closed room containing sulphuretted hydrogen gas.

Black for Silk Pieces.—After the pieces have been cleaned in the usual manner, take them singly through a hand-warm beck containing a little turmeric and sulphuric acid. Let them then steep over night in a beck of nitrate of iron at 6° B. Wash, and enter in a beck of logwood and fustic, gradually raising the heat. If the pieces on leaving this beck appear rusty, take them through a very weak sour. Otherwise enter at once in a beck at a hand-heat, in which have been dissolved 2 lbs. soda crystals and 3 lbs. double muriate of tin. Let steep till the black is fully developed.

Black for Silk Garments (1 lb.).—Boil 1 lb. galls in sufficient water to dye the silk. Strain the decoction, and lay in the goods thoroughly cleaned, and steep over night. In the morning lift, dry, and enter in a warm beck with half a pound of muriate of iron and half a pound of black liquor. Work till deep enough; wash, and take through water at a hand-heat, slightly soured with muriatic acid. If the goods have a cotton warp the sour must be still weaker.

Black for Garments (2½ kilos.).—Wash with soda and soap; rinse, and pass through a cold bath containing one quarter kilo. sulphuric acid; rinse again, and steep over night in cold nitrate of iron at 7° B. Lift, rinse twice, and dye for forty-five minutes in the decoction of half a kilo. of fustic at 75° C. Enter in a fresh beck made up with 1 kilo. 130 grms. of logwood and 1 kilo. curd soap, raising the heat gradually from a hand-heat to a boil. Work till the silk, on being held up to the light, appears a dark greenish blue. Rinse, and finish with mucilage of gum tragacanth.

Black on Silk Waste (5 kilos.).—Wet out in hot water; enter in nitrate of iron at 10° B., and steep five hours; rinse, and enter in a fresh beck of nitrate of iron of the same strength for five hours, rinse, and whiz. Dissolve one half kilo. of solid bark extract in water, heat it to 55° C., enter the silk, and work till it is a dark green; lift, and whiz. Make up a new beck with 2 kilos. logwood, 1 kilo. curd soap, and 130 grms. extract of bark. Heat to 37° C., enter the silk, and raise slowly to a boil. Rinse well.

Aniline Blue.—Dye in a beck of 1 part of the soap-lye used for ungumming the silk, mixed with 2 parts water. To this add as needed a solution of aniline blue in alcohol, and a little tartaric acid. When dyed, wash and raise in water, to which a little sulphuric acid has been added, and dry.

Gros Bleu (5 kilos.).—Work for two hours in nitrate of iron at 10° B., lift, and stretch out. Work in a lye of 1 kilo. of curd soap at 92° C., and stretch again. Work for two hours in nitrate of iron at 20° B., and soap again in the old lye, to which one half kilo. of soap has been added. Take seven times through solution of prussiate at 35° C., lift, add 2½ kilos. of muriatic acid, re-enter, and work till level. Rinse, and enter in a beck of 5 kilos. catechu and 250 grms. tin crystals at 75°, and steep for three hours. Enter in black liquor at 5° B., rinse, and place it at 37° C. in a clear beck of 1½ kilo. logwood liquor and 1 kilo. of alum. Work in this seven times, lift, heat to 75° C., re-enter, and dye up to shade. Rinse, and soften in a mixture of potash and olive oil.

This formula is given as a specimen of what should be avoided. It is intended rather to *weight* than to *dye* the silk. For the latter purpose the iron is excessive, and the catechu totally superfluous.

Bronze on Silk Garments.—Keep each dress three or four hours in water containing one half lb. alum in solution; lift, rinse, and dye with 3 quarts logwood liquor, 5 quarts sapan, and 5 quarts of fustic liquor, at a hand-heat. Let steep for thirty to forty-five minutes; add a little soap, give three or four more turns, wring, wash, and finish.

Reddish Brown.—Boil up to 4 ozs. archil and 6 ozs. turmeric, add 1½ oz. vitriol to the decoction, enter the silk, and work till it is a bright orange. Lift, wash, and enter in a nitrate of iron beck, where it is left for fifteen minutes. Wash, and dye cold in fustic liquor.

If a deeper shade is required steep longer in the nitrate of iron, add a little bark to the fustic beck, and raise gradually to a boil.

A peculiar red is produced by topping with magenta when the silk comes out of the archil and turmeric beck.

Brown (5 kilos.).—Steep the ungummed silk over night in solution of alum at 30° B.; take out the the next morning and dye in a beck of logwood, peachwood, and fustic, as the shade requires. For medium shades 600 grms. of each of the three woods suffices. The beck is kept at 75° to 93° C., and the goods are handled from thirty to sixty minutes.

Gold Colour (2 lbs.).—Boil 1 lb. annotta for half an hour with 2 lbs. soda crystals, and strain off the liquid. Of this add to the dye beck more or less, according to shade; enter the silk, previously ungummed, and dye up to shade. Lift, and pass through a solution of alum, 10 grms. per litre. If a redder tone is required add a little magenta to the alum beck.

Aniline Green.—Dye with aldehyde green at 45° to 50° C.; wash, and top in a fresh beck with iodine green and picric acid, to which a little acetic acid is added.

Iron Grey for Thread (5 kilos.).—The silk after boiling is twice washed and mordanted in half a kilo. of sulphuric acid and 1 kilo. nitrate of iron, if the shade be light. For medium shades 2 kilos. nitrate of iron are used, and for heavy shades 4 kilos. Pass the silk seven to nine times through the beck, and wash twice. It is then dyed at 43° C. in a beck made up of logwood, peachwood, and fustic, according to shade, and finally finished off in a fresh beck at 50°, and washed.

Gris d'Aniline (Nigrosine.).—This colour plays a very important part in silk dye-works, being used for all greys, modes, dark blues, plums, and Prussian greens. The shades are not costlier than similar shades from the woods, and the same beck can be used for days in succession. The gris d'aniline soluble in alcohol is preferable to the kind soluble in water, which gives flat shades. The silk is dyed at a boil, with the addition of soap and sulphuric acid. With the addition of archil and young fustic or berries all tones of grey, mode, and olive can be produced.

For dark greens, turmeric is used with aniline blues, and gris d'aniline greens may be brightened by topping with picric acid in a fresh beck. Dark blues are got with aniline blue and gris d'aniline.

In dissolving the colour, filter carefully before use. Per kilo. silk take a pail of soap-lye, make up the beck with water, add 65 grms. of sulphuric acid, and heat to 60° C. Add the dissolved colour, enter the silk, and raise to a boil; wash well afterwards.

Ponceau.—Enter in a slightly acid beck of yellow coralline at 75° C., and dye to shade. Rinse, and enter in a fresh beck of magenta, with a yellowish tone, at 40° to 50° C.

Cochineal Scarlet on Silk in one operation (1 lb. ungummed silk.).—Enter in a beck of 1½ to 2 ozs. annotta, previously dissolved. Raise to about 150° Fahr., and in this work for fifteen to twenty minutes, increasing the heat nearly to a boil. Wash and dye as follows:—Enter in a lukewarm beck of 4 ozs. tin solution and 8 ozs. cochineal liquor. Give a few turns and steep for eight hours. Lift, and wash in water.

The tin solution is made by dissolving 8 ozs. tin in a mixture of 1 lb. nitric acid at 30° B., and 2 lbs. muriatic acid at 22° B.

The cochineal liquor is made by boiling ground cochineal for an hour, adding for each pound of cochineal 6 ozs. of tartar crystals, and then boiling for another half hour. Strain for use.

Ungumming Silk.—Make up a beck with a quarter lb. soap per lb. of silk, and work in this on rods till the varnish is removed, without raising to a boil. Turn the hanks inside out, so that the part which lay next to the rods may be fully exposed to the lye. Enter in a second soap-bath, containing 3 ozs. soap per lb. of silk, and work for fifteen minutes.

White on Silk Waste (5 kilos.).—Boil with 1½ kilo. curd soap, rinse, and tint in a cold fresh beck of 400 grms. soap, to which a suitable quantity of methyl violet has been added.

Yellow on Silk Waste (5 kilos.).—I. *Fast.*—Boil with 1 kilo. curd soap, rinse, and enter in red liquor at 10° B., and steep for five hours. Lift, rinse, and dye in a cold decoction of 5 kilos. young fustic, rising slowly to a boil. II. *Inferior.*—Boil with soap as above; rinse, and dye in a fresh beck with 180 grms. of picric acid.

French Purple.—Mix the paste, as sold, with an equal weight of oxalic acid, boil in water, and filter. The colouring matter goes through in solution. The dye beck is made slightly ammoniacal, and to it the dye liquid is then added. Silk is then dyed by simple immersion.

Wool may be dyed in the same manner, but cotton and linen must be either treated with albumin or prepared as for turkey red.

Preparation and Dyeing of Woollen Stuffs.—Woollen is banded with twine into spindles in the same way as cotton and silk, previous to being put under operations for scouring or dyeing. It is then steeped over night in soap lye or old alkaline solutions, and then scoured through clean soap to remove all oil or grease that may be upon the wool; or, what is more common, a scouring liquor is prepared with 1 lb. of soft soap and 1 lb. of common soda, or half a pound of soda ash, in 10 gallons water, and scoured through this.

This is the only preparation that new wool is subjected to previous to dyeing.

For re-dyes every care should be taken to remove all grease or oil first, or no good dye can follow. This is done by steeping and scouring in soap and soda. If the remaining colour be unequal or dark, the goods are steeped or wrought for a little in a sour made up of bisulphate of potash—dissolving 2 ozs. to the gallon of water.

Woollen is always dyed hot; the liquid usually being near to the boiling point, which necessitates its being dyed in a boiler. Iron vessels are not used for this purpose. Copper, and tinned copper, is most generally used. The dyestuffs, such as ground wood, are generally put into the boiler and the goods wrought with it, but it is cleaner to make a decoction and use the clear liquor.

All washings are made in cold water, except warm be specified in the directions.

In the following receipts, where not otherwise specified, the quantity of goods referred to is 10 lbs., whether in cloth or yarn :—

Black (100 lbs.).—Boil for an hour and a half with 3½ lbs. chromate of potash, 2 lbs. argol, and three-quarters lb. blue vitriol. Cool in the liquor. Dye for an hour and a half at a boil with 70 lbs. logwood and 7 lbs. fustic. Sadden with 2 lbs. copperas.

Black for Fulling (50 kilos.)—Boil for two hours in

Logwood,	25	kilos.
Fustic,	10	"
Sumach,	10	"
Argol, red,	2½	"

Sprinkle it with the solution of—

Copperas,	2½	"
Blue vitriol,	1½	"

and boil again for an hour. If the black is to have a blue tone cool down the kettle, and bloom with 2½ kilos. ammonia. Rinse, and dry. If a jet black is required, add instead of ammonia 1½ kilo. chromate of potash, and boil for fifteen minutes longer.

Black for Knitting Yarns (25 kilos.).—Boil for forty-five minutes with 875 grms. chromate of potash, 100 grms. blue vitriol, 100 grms. argol, 200 grms. sulphuric acid. Take through water and boil with 15 kilos. logwood for forty-five minutes.

Black.—Work for twenty minutes in a bath with 8 ozs. camwood; lift, and add 8 ozs. copperas; work another twenty minutes; then withdraw the fire from the boiler, and submerge the goods in the liquor over night; then wash out. Into another bath, with 5 lbs. logwood and 1 pint chamber lye, work for an hour; lift, and add 4 ozs. copperas; work in this half an hour longer; wash, and dry.

Brown.—Work for an hour in a bath made up with 2 lbs. of fustic, 2 lbs. of madder, 1 lb. of peachwood, 4 ozs. of logwood; then lift, and add to the bath a solution of 2 ozs. of copperas, and work half an hour in this; wash out, and dry.

Brown.—Work for an hour in a bath of 4 lbs. of fustic, 2 lbs. of camwood, half a pound of logwood; lift, and add to the bath 4 ozs. of copperas; work half an hour in this; wash, and dry.

Amaranth (12½ kilos.).—Make up a beck with 50 grms. magenta and 350 grms. picric acid. Enter cool, and raise gradually to a boil.

Superior Amaranth (5 kilos.).—Make up a beck with 380 grms. perchloride of tin; steep the goods for forty-five minutes at a boil, and for four to five hours longer as it cools. Rinse, and dye as above. Pass through a solution of 150 grms. gum arabic, or 250 grms. glue, and dry.

Crimson.—Work in a bath for one hour with 1 lb. cochineal paste, 6 ozs. dry cochineal, 1 lb. of tartar, 1 pint of dichloride of tin ("single muriate"); wash out this, and dry.

Fast Red Brown (5 kilos.).—Work for fifteen minutes in a boiling solution of 1¼ kilo. lime; boil for twenty minutes with 1¼ kilo. alum, 340 grms. argol, 70 grms. bran. The next day rinse, and dye for an hour at a boil with 400 grms. cochineal and 340 grms. argol. Rinse again, and boil for thirty minutes in the decoction of 2 kilos. peachwood and 170 grms. cudbear. Bloom in the same beck, adding 670 grms. soda.

Red Brown (5 kilos.).—Prepare by boiling forty-five minutes with 80 grms. chromate of potash, 16 blue vitriol, 375 argol, 32 sulphuric acid. Dye with one quarter kilo. fustic and 1½ kilo. peachwood at a boil. Sadden by gradually adding the clear decoction of one quarter kilo. logwood.

Darker Brown (5 kilos.).—Prepare as above, and dye for thirty minutes at a boil with 2 kilos. peachwood and one-fourth kilo. fustic, adding, as required, the decoction of 1 kilo. logwood.

Sang de Bœuf (5 kilos.).—Same prepare; dye at a boil for thirty minutes with the clear decoction of 2 kilos. peachwood and 120 to 150 grms. logwood.

Dark Sang de Bœuf (5 kilos.).—Prepare with 130 grms. bichrome, 40 grms. blue vitriol, 380 grms. argol, 40 grms. sulphuric acid. Let cool in the liquid, and dye by boiling thirty minutes with 2 kilos. peachwood, one-fourth kilo. fustic, and 1½ kilo. logwood. The woods are used in the form of clear decoctions, and added by degrees.

Yellowish Brown (100 lbs.). — Boil for an hour with 3 lbs. chromate of potash, and dye in a fresh kettle with 20 lbs. fustic, 40 lbs. sanders, 10 lbs. turmeric, boiling for another hour.

Fast Cherry Brown for Yarns (10 lbs.).—Boil for an hour with 2 ozs. chromate of potash, 2 ozs. argol. Let cool in the liquid; lift, rinse, and enter in a fresh beck with 3½ lbs. sanders, a quarter of a pound turmeric, and half an ounce magenta, and boil to shade.

Bronze Brown (50 kilos.).—Prepare for one hour with 12 kilos. alum and 5 kilos. argol. Let it grow cold in the liquid, rinse, and dye with 10 kilos. fustic, 2½ kilos. peachwood, and 2 kilos. logwood. These preparations are modified according to the shade.

Havanna Brown (50 kilos.).—Prepare as above, and dye with 5 kilos. peachwood and 2½ kilos. fustic. Sadden to shade with logwood liquor.

Bismarck Brown, Fast (5 kilos.).—Make up a beck with 2¼ kilos. fustic, 1½ kilo. madder, 375 grms. camwood, and 250 sumach. Enter, and steep for an hour at 85° C. Lift, and add to the beck 125 grms. blue vitriol. Cool down to 75° C., and steep till the shade is reached. A block-tin dye pan is recommended.

Bismarck Brown, Inferior (5 kilos.).—Take 250 grms. sulphate of soda, 160 grms. sulphuric acid, 32 grms. picric acid, 320 grms. archil, and extract of indigo to shade. Boil, cool down to 75° C., enter, and work for an hour. A wooden dye beck may be used.

Bismarck, for Yarns (10 lbs.).—Prepared tartar 1 lb., sulphuric acid 1½ oz., turmeric 1½ lb., archil 2 lbs., extract of indigo 3 ozs. Boil up, cool, enter, and work to shade.

Red Brown on Yarns (25 lbs.).—Make up a beck with 2½ lbs. argol and 9 lbs. archil; boil up, cool, enter the yarn, and dye at a boil. If too bright add a little extract of indigo; if a yellower tone is desired add extract of fustic.

Chamois Brown (100 lbs.).—Boil for an hour with 7½ ozs. galls, 2 lbs. argol, 2½ lbs. madder, and 7½ lbs. cudbear, and sadden with half a lb. copperas.

Brown (10 lbs.).—Dye at a boil with 2½ ozs. extract of indigo, 4 lbs. archil, and a quarter lb. to half a lb. turmeric, adding 2 lbs. sulphate of soda and 1 lb. sulphuric acid.

Reddish Dark Brown (200 lbs.).—Boil for one and a half hour with 60 lbs. fustic, 12 lbs. logwood, 4 lbs. turmeric, 60 lbs. sanders, 5 lbs. argol, and sadden with 8 lbs. copperas.

Dark Brown (100 lbs.).—Boil for an hour with 2½ lbs. chromate of potash, 2½ lbs. argol, and the same weight of blue vitriol, let cool in the liquor; take out, and dye with 15 lbs. fustic, 1¼ lb. logwood, 10 lbs. sanders, and 5 lbs. madder; boil for an hour, and then sadden with 20 to 24 ozs. of copperas.

Brown (for piece goods, 2 pieces).—Boil for an hour with 1 lb. chromate of potash, 1 lb. prepared tartar, and 1 lb. sulphuric acid; pass through cold water, and dye in a fresh beck with 30 lbs. peachwood, 6 lbs. fustic, and logwood if needful.

Brown on Merino (25 kilos.).—Take 8 kilos. logwood, 2 kilos. fustic, 1 kilo. sulphate of soda, 1 kilo. argol, 1 kilo. sulphuric acid; boil the goods in this mixture for forty-five minutes; add a little more logwood, and if needful sadden with extract of indigo.

Bronze Brown (25 kilos.).—Add to the above mixture 1 kilo. sulphate of alumina, a little extract of indigo, 1 kilo. tartaric acid, 2½ kilos. fustic, 1 kilo. sulphuric acid, and boil as above.

Brown on Alpaca (5 kilos.).—Boil with a quarter kilo. chromate of potash and a quarter kilo. argol; dye in 2 kilos. peachwood; rinse, and pass through a beck of stannate of soda at 2° B.; enter in a logwood beck at 2½° B., and finally sadden with chromate of potash.

Cerise for Yarn (10 lbs.).—Sanders, 4 lbs.; cudbear, 1⅓ lb. Boil for one and a half hour; lift, and add three quarters lb. alum; re-enter, and work for fifteen minutes without rising to a boil; lift, and top in a fresh beck with 1 oz. to 1½ oz. magenta.

Chamois for Knitting Yarns (5 kilos.).—Boil up the beck with chloride of tin, and take 250 grms. oxalic acid, 200 grms. tin crystals, and cochineal to shade; no flavin.

Dark Crimson (100 lbs.).—Boil for ninety minutes with 50 lbs. fustic, 10 lbs. sanders, 3 lbs. turmeric, 2 lbs. madder, 6 lbs. argol, and sadden to shade with 1 to 2 lbs. copperas.

Scarlet (12 lbs.).—Boil together 1 lb. cochineal and 7 ozs. bark; add 12 ozs. tartar and 1 pint scarlet spirits; enter at 200° Fahr.; boil for one hour, and wash. The goods before dyeing should be scoured, and then washed in one water.

Light Grey for Yarns (10 lbs.).—Boil with 0·3 kilo. argol, 0·15 kilo. alum, and 0·3 kilo. ground logwood, and sadden with 0·075 kilo. copperas.

Mode Grey on Yarns (10 lbs.).—*Fast.* Boil for three quarters of an hour with 1 lb. white argol, 2½ ozs. ground galls, a quarter oz. sanders, and sadden with half an oz. copperas; boil for half an hour longer; take out, rinse, and dry.

Inferior.—Boil with 2 lbs. sulphate soda, 2 lbs. prepared tartar, 2½ ozs. archil, half an oz. extract of indigo, and about an eighth oz. picric acid.

Silver Grey (pieces, 1 piece 1 ell wide).—Make up a beck with 2 ozs. alum, 2 ozs. tartar crystals, half an oz. soda ash; add logwood liquor till the shade is reached; dye at 75° C. After dyeing take rapidly through cold water. For a redder tone add cudbear, and for a yellower, decoction of fustic.

Red.—Work half an hour in a bath with 1 oz. of bichromate of potash, 1 oz. of alum; wash out this through cold water; then work for half an hour in another bath with 3 lbs. of peach or lima wood; lift, and add 1 oz. of alum; work in this for twenty minutes; wash, and dry.

Claret Red.—Work for an hour in 5 ozs. of camwood; lift out, and expose until the goods are well drained and cold; in the interim add to the bath with the camwood 4 ozs. of copperas, 2 ozs. of alum, 8 ozs. of logwood; work the goods in this for half an hour; wash, and dry.

Madder Red (12½ kilos.).—Add to the needful quantity of water 1¼ kilo. of scarlet composition and as much sulphate of alumina, with one half kilo. bran and one half kilo. ground white argol.

For the dye beck stir up 2½ kilos. of good French madder, and pour into a fresh beck of water. Heat, enter, work for one hour, and take out and rinse.

Rouge de Gravelotte.—This is merely a cochineal red, got up in the common way with cochineal, tin crystals, and oxalic acid, and topped with magenta, or preferably with saffranin.

Rose de Chine.—Dissolve gladioline in boiling water, and filter. Add the solution to the dye beck. Dye hot, and then add a solution of aniline orange.

Rose and Crimson.—Dye, according to shade, at 75° C., in a mixture of 2 parts magenta, 2 parts silicate of soda, 1 part sulphate of soda, and a little picric acid. After dyeing handle the yarns for fifteen minutes in a fresh cold beck, with 2 parts of hyposulphite of soda.

Deep Rose (5 kilos.).—Boil with one quarter kilo. sulphate of alumina, 300 grms. bichloride of tin, 330 grms. tartar, and dye at a boil in a fresh beck with 200 grms. ammoniacal cochineal.

Scarlet with Lac, Alpaca (24 lbs.).—Grind the lac-dye fine, put 4 lbs. in a stoneware mug, and add to it, stirring all the time, 4 lbs. lukewarm water, acidified with three-quarters of a lb. vitriol. Let settle for twenty-four hours, and then add to it, stirring well, 2½ lbs. muriate of tin. After some hours prepare for dyeing; add to the dye beck 1 lb. of bran, and when boiling put to it 1½ lb. of tartar in powder, and 6 ozs. muriate of tin. Skim carefully, and add half the lac-dye liquor, boil a few minutes, and enter the wool. Boil for half an hour, take out the wool, and pour in the remaining dye liquor; re-enter the wool, and boil for forty-five minutes longer.

Lac Scarlet.—Work for half an hour in a bath with 1 lb. of tartar, 8 ozs. of sumach, 2 lbs. of lac; lift, and add about a gill of bichloride of tin (double muriate), and work in this for half an hour; lift, wash, and dry.

Lead Colour (125 kilos.).—Boil for an hour with 10 kilos. logwood, 1 kilo. myrobalans, one half kilo. fustic, one quarter kilo. argol, and one half kilo. alum; then sprinkle the solution of 1¼ kilo. into the beck, and boil for thirty minutes longer.

Pink.—Work one hour in a bath with 1 lb. of tartar, 8 ozs. of alum, 1 lb. of cochineal paste, 1 gill measure of red spirits; wash out in cold water, and dry.

Ponceau for Pieces (2 pieces).—Boil for an hour with 1 lb. chromate of potash, 1 lb. prepared tartar, and 1 lb. sulphuric acid. Take through cold water, and dye in a fresh beck with the extract of 20 lbs. fustic, adding peachwood as needed. Wash, and dry.

Fast Ponceau for Piece Goods and Loose Wool (50 kilos.).—I. Boil for fifteen minutes one quarter kilo. bichloride of tin and 1¼ kilo. bark. Add 2 kilos. oxalic acid, 1½ kilo. tin crystals, one half kilo. white tartar, and 3¼ kilos. ground cochineal. Boil well, cool down, enter the wetted pieces, and boil from forty-five to sixty minutes.

II. Mix 5 kilos. nitric acid and 3 kilos. muriatic, and dissolve in the mixture 5 kilos. grain-bar tin; then dissolve in the liquid tin crystals till it marks 50° B.; 2½ kilos. of this spirit and 2½ of white argol constitute the prepare. Boil the goods in this for an hour, let cool in the liquor, drain, and dye with 5 kilos. cochineal and 2½ young fustic. Rinse gently. Ponceaus for milling must be made two shades yellower than the pattern, and a very acid prepare must be used.

Ponceau for Knitting Yarn (25 kilos.).—Dye in an old chamois beck, adding 1¼ kilo. oxalic acid, 1 kilo. tin crystals, and 3 kilos. cochineal.

Yellow.—Work for twenty minutes in a bath with 8 ozs. of tartar, 8 ozs. of alum, lift, and add to the bath 2 lbs. of bark, 8 ozs. of sumach, 8 ozs. of fustic, 1 pint of red spirits; work in this for forty minutes; wash out, and dry.

Dark Yellow (5 kilos.).—Prepare with 170 grms. sulphate of alumina, 250 grms. tartar, 500 grms. sulpho-muriate of tin. Place in the same beck 1¼ kilo. of bark tied up in a bag, and a little glue. Skim carefully, and when all dirt is removed take out the bag and enter the wool. Sadden, if needed, with cudbear. A greenish reflection may be produced with arsenite of soda.

Yellow for Shoddy (100 lbs.).—Clear out the beck with a little bichloride of tin, and boil 50 lbs. of bark for thirty minutes. Then add half a lb. of white glue, previously dissolved in hot water. Boil up again, and skim. In the clear liquid dissolve 3 lbs. oxalic acid, 3 lbs. tin crystals, and 1 lb. perchloride of tin, and boil the goods for an hour.

Straw Colour (10 lbs.).—Boil for forty-five minutes with 6 ozs. alum, 3 ozs. argol, half a lb. fustic, and half a lb. madder.

Orange.—Work for forty minutes in a bath with 2 lbs. of sumach, 3 ozs. of cochineal dry, 1 lb. of fustic, 8 ozs. of tartar, 1 pint of red spirits; wash out this, and dry.

Orange for Shoddy.—Boil with 15 lbs. bark, 1 lb. cochineal, 3 lbs. argol, 3 lbs. tin crystals, and 3 lbs. tin composition.

Sky Blue.—Work in a bath for half an hour with 8 ozs. of argol, 1 lb. of alum, 1 gill of indigo extract; wash out this, and dry.

Different depths of shade may be made by varying the quantities of indigo extract.

Wood Blue on Yarns (5 kilos.).—Boil for half an hour with 667 grms. alum, 320 grms. argol, 200 grms. extract of indigo. Take out, run off half the contents of the kettle, and dye at 50° C., with 1 to 1½ kilos. of logwood.

Dark Blue to bear milling on Cloth for Ladies' Paletots (180 kilos.).—Ground slightly in the vat, rinse, and enter in a beck made up with 2½ kilos. of soluble iodine violet. Begin cool, boil for an hour, and steep for three hours longer without boiling. Take through pure water to which 18 kilos. sulphuric acid has been added; wash, whiz, and dry.

Fast Dark Blue (50 kilos.).—Ground in the vat, take through warm water, and boil for an hour with chromate of potash, half a grm.; alum, 5 kilos.; blue vitriol, a quarter kilo.; tin crystals, 180 grms. Dye with 10 kilos. Domingo logwood, adding half a kilo. sulphuric acid; rinse, and dry.

Royal Blue (for pieces 60 lbs.).—Boil for an hour with 2 lbs. red prussiate and 1 lb. bichloride of tin, and add gradually while boiling 4 lbs. sulphuric acid. Boil for forty-five minutes longer; take out, rinse, and bloom with magenta in a fresh beck at 75° C.

Navy Blue for Pieces, Yarn, or Rags (10 lbs.).—*First Method.*—Wash with soap, and boil with 5 ozs. argol and 5 ozs. chromate of potash. Rinse, and dye at a simmer with 1 lb. logwood and a quarter oz. aniline blue.

Second Method.—Boil at once with a quarter oz. aniline blue, 1 oz. extract of indigo, 1½ lb. alum, and a half lb. oil of vitriol. Darken, if requisite, with archil.

Bright Reddish Blue to bear milling (10 lbs.).—I. Dye up a light blue in the vat, rinse, take through a bran beck, and rinse again. Boil for thirty minutes with half a pound of perchloride of tin, and dye in a fresh beck with methyl violet. II. Boil forty-five minutes with 1 oz. chromate of potash, half an oz. blue vitriol, half a lb. argol, half a lb. alum, and half an oz. tin crystals. Let cool in the liquor; lift, rinse, and make up a fresh beck with 1 lb. logwood. Add 2½ ozs. of sulphuric acid, and boil for three quarters of an hour.

Pigeon Blue.—Work in a bath for forty minutes with 2 ozs. of chrome, 4 ozs. of alum, 1 oz. of tartar;

wash from this in cold water, and then work for half an hour in another bath with 3 lbs. of logwood; lift, and add 1 oz. of verdigris; work for fifteen minutes, and wash and dry.

Modes on Alpaca and Vicuna (100 lbs.).—*Shade* 1. --Boil with 2 lbs. argol, 3 lbs. madder, three quarters of a lb. fustic, one quarter lb. ground logwood, half a lb. galls, half a lb. cudbear, and 2 ozs. extract of indigo. Sadden with one quarter lb. copperas.

Shade 2.—2 lbs. argol, 5 lbs. madder, 1½ ground fustic, half a lb. galls, half a lb. cudbear, and 1 lb. ground logwood. Sadden with 1 oz. copperas.

Shade 3.—Boil with 1½ lb. bichromate of potash and 1 lb. argol. Dye up with three quarters of a lb. ground logwood, 1 lb. ground fustic, 8 lbs. madder, and 4 ozs. galls. Sadden with 1 oz. copperas

Shade 4.—Boil with 8 lbs. madder, 3 lbs. caliatur wood, 1 oz. galls, 1 lb. argol, and 1¼ lb. ground fustic. Sadden with 2 ozs. copperas and 4 ozs. cudbear.

Shade 5.—1 lb. argol, 4 lbs. madder, 1¼ lb. ground fustic, 1 oz. galls, and 8 ozs. cudbear. Sadden with 1½ oz. copperas.

Shade 6.—Boil with 4 lbs. alum and 1 lb. argol, and dye with 2½ lbs. ground fustic and 4 ozs. madder. Sadden with copperas, 1 oz.

Maroon for Yarn (10 lbs.).—Boil for an hour with 2 ozs. chromate of potash, 2 ozs. sulphuric acid. Let cool in the liquid, rinse, and dye in 2½ lbs. fustic, 3½ lbs. sanders, 1 lb. madder. If the shade is not dark enough, sadden with chromate of potash. Lift and rinse.

Fast Maroon (50 kilos.).—Boil up 10 kilos. of catechu in water; make up a beck and add the decoction of 5 kilos. logwood and 2½ kilos. argol. Boil the goods for two hours, lift, and add to the beck 2 kilos. chromate of potash, 1 kilo. blue vitriol; re-enter the wool, boil from thirty to sixty minutes, and rinse.

Mulberry (5 kilos.).—Boil for an hour and a half with 80 grms. chromate of potash, 200 grms. alum, 48 grms. blue vitriol, and 160 grms. prepared tartar. Let cool in the liquor, or rinse immediately. Then dye in a beck of 875 grms. logwood, 2½ kilos. camwood, and half a kilo. cudbear, boiling for an hour and a quarter.

Apple Green.—Work for half an hour in a bath with 1 oz. of chrome, 1 oz. of alum; wash through cold water, and then work for half an hour in a second bath with 2 lbs. of fustic and 8 ozs. of logwood; wash, and dry.

A variety of this shade can be obtained by diversifying the proportions and quantities.

Green.—Work for fifteen minutes in a bath with 5 lbs. of fustic, 2 ozs. of argol, 5 ozs. of alum; lift, and add 1 gill of indigo extract; and then work for half an hour, and dry.

If the green seem too yellow, a little more extract of indigo may be mixed with the others.

Fast Green.—This is first dyed blue in the indigo or woad vat, according to the depth of green required, and then work for an hour in a bath with 4 lbs. of fustic, 2 lbs. of alum, and dry out.

Dyeing the blue lighter than is required for the green, and adding to the bath with the fustic a little logwood, will give the required depth and a good shade; but the colour is not so fast.

Fast Green for Yarns (10 lbs.).—Sulphate of alumina 1½ kilos., argol 0·2 kilo., extract of indigo 0·3, and sulphuric acid 0·125. Dye the yarn a blue in this mixture; lift, add decoction of fustic as required, re-enter, and dye to shade.

Dark Blue Green (10 lbs.).—Prepared tartar 0·5 kilo., sulphate of alumina 1 kilo., sulphuric acid one-fourth of a kilo., extract of indigo half a kilo., picric acid one-fourth of a kilo. Boil up together, enter the wetted yarns, and boil for an hour.

Russian Green (100 lbs.).—Boil for 90 minutes with 1½ kilo. chromate of potash, 1 kilo. blue vitriol, and 1½ kilo. alum. Take out, cool, and dye in 10 kilos. logwood and 6 to 7 fustic.

Olive.—Work for an hour in a bath with 10 ozs. of fustic, 8 ozs. of logwood, 4 ozs. of madder, 2 ozs. of peachwood; lift, and add to the same bath 4 ozs. of copperas in solution, and work for half an hour, and dry.

Olive (100 lbs.).—I. Logwood 10 lbs., fustic 20 lbs., alum 2½, argol 5 lbs., turmeric 5 lbs. Boil for twenty-five minutes, and sadden in the same liquor with 3 lbs. copperas. The yellower the shade the more turmeric must be added. II. Give a light blue ground in the vat, and boil for two hours with 2 lbs. alum, 1 lb. argol, 12 lbs. turmeric, and 90 lbs. fustic. Sadden in the same with 2 lbs. copperas.

Olive on Yarns (5 kilos.).—Boil with prepared tartar 384 grms., blue vitriol 80 grms., archil 1½ kilo., turmeric 200 grms., sulphate of indigo 160 grms.

Wine Colour.—Work the goods for an hour in a bath with 4 lbs. of cudbear, and dry.

If a darker shade be required, give more cudbear; if the tint be desired bluer, add, after half an hour's working, 1 gill of ammonia; if a redder tint is wanted, add a wine glassful of hydrochloric acid.

If the acid be added, the goods should be washed before drying.

Light Violet.—Work for an hour in a bath with 4 ozs. of cudbear, 4 of logwood, 2 of barwood or camwood, 2 of peachwood; lift, and add 2 ozs. of alum in solution, and work half an hour, and dry.

Puce.—Work in a bath for one hour with 10 ozs. of logwood, 1 oz. of camwood, 8 lbs. of cudbear; lift, and add 2 ozs. of copperas in solution; work half an hour, and dry.

Drab (100 lbs.).—Boil for two hours with 1 lb. argol, 4 lbs. fustic, 6 ozs. logwood, 12½ ozs. turmeric, and 2½ lbs. madder. Sadden with copperas as needful.

Brown Drab.—To the dye bath add 2 ozs. ground madder, 1 oz. peachwood, 2 ozs. of logwood, 6 of fustic, and work in this for thirty minutes; lift up, and add 3 ozs. of copperas in solution; mix well, and work the goods in this for other thirty minutes; wash, and dry.

This shade can be greatly varied, either by altering the quantity of stuffs, or the proportions of any of them; if a redder tint be required, add more peachwood or madder; the latter gives the drab hue: if more yellow, add fustic; if more slate or black, add logwood, and *vice versâ.*

Stone Drab.—Into the proper proportion of water add 1 oz. of peach or lima wood, 2 ozs. of logwood, half an oz. of fustic; work in this for twenty minutes, and then lift out, and add to the dye bath 1 oz. of sulphate of iron in solution; stir well, and work in this for another half hour; lift out, and expose to the air for a short time; wash, and dry.

A diversity of shades may be dyed by altering the quantities and the proportions of the dyestuffs.

Slate.—Work for half an hour in a bath with 8 ozs. of logwood, 1 oz. of fustic; lift, and add to the bath a solution of 1 oz. of alum, half an oz. of copperas; work in this half an hour; wash, and dry.

Different tints of this colour can be obtained by varying the stuff; if more blue be required, use less alum and more copperas; if more to the purple, less fustic and more alum; and so, by a very little practice, any particular hue can be dyed.

New Colours on Wool, &c.—*Aurine Orange.*—Dissolve the colour in water to which a little soda has been added. Now add acetic acid till the beck begins to grow turbid. In this state it dyes wool readily.

Another process is to add the colour to boiling soap lye, and then to add gradually an acid till turbidity appears. This method is also applicable to silk.

Coralline (peonine) scarlets may be obtained in the same manner.

Aniline Black (2 lbs.).—Dissolve 3 ozs. permanganate of potash and 4½ ozs. Epsom salts in 5 gals. of hot water. When cold, enter the wool, and allow it to steep till the liquid only looks slightly yellowish; wring, and enter in a cold beck made up with 12 ozs. aniline oil, 20 ozs. muriatic acid, and 2 gals. water; lift, press, and wash in water containing a little soda. Enter in a solution of bichromate of potash, containing one third oz. bichromate to 2½ gals. until it acquires a deep black; wash, and dry. The aniline beck should be preserved, and if portions of aniline oil are added from time to time may be used separately.

Eosin Pinks and Roses (100 lbs.).—Dye in the watery solution at a boil, a little acetic acid having been added; then boil in water containing 2 lbs. of oxalic acid and 2 lbs. acetate of alumina.

Nicholson Blue (5 kilos.).—Boil the wool in the alkaline beck to shade in the usual manner, using about 50 grms. of Nicholson blue and 150 grms. soda ash; whiz, and then boil for fifteen minutes in a beck with half a kilo. alum and a quarter kilo. tartar. Avoid excess of colour.

If a very greenish shade is desired, then instead of boiling in the above mixture use a cold beck of a quarter kilo sulphuric acid. It is not prudent to use silicate of soda in place of soda ash.

Pomona Green.—Make up a beck with silicate of potash enough to give it a soapy feel. Wash the wool at 160° Fahr. till thoroughly wetted. Meantime dissolve the colour in a little cold water; add the clear solution very gradually to the beck, and work the wool till the required shade has been reached. To judge of the proper point some spare swatches are dyed in the same beck, and one of them is from time to time taken out and steeped in very dilute acetic acid, which renders the colour visible. When the shade is reached, lift and place the wool in a beck of very dilute acetic acid at 160° Fahr., to which a little tannic acid has been added. If a yellower tone is required, a little picric acid may be added.

For alpaca take per 5 lbs. of goods 2 ozs. aniline green, 2 ozs. strong ammonia, and the same weight of silicate of soda. Wash in this; lift, and take through a tannin beck; return to the colour beck; and lastly, raise in moderately strong acetic acid.

Methylaniline Green.—This colour is not decomposed by boiling, and dyes wool, worsted, and silk without any mordant.

Aniline greens are sometimes sold as insoluble tannates. These are dissolved in exceedingly weak sulphuric acid. The solution dyes wool and silk. Dale recommends to prepare wool with a dilute solution of chloride of lime, when it takes up the colour better.

Burl-Dyeing with Aniline Green for Light Green Cloth (5 kilos.).—Boil out 1½ kilo. sumach in water, and steep for two hours in the clear liquid at 80° R., turning it frequently. Take out, wring out, and dye in a fresh beck at a hand heat with methyl green and a little picric acid.

Methyl Green (yarns).—Ground with Nicholson blue, and top with a mixture of methyl green and picric acid according to shade.

Pansy, Bright and Fast (100 lbs.).—Ground to shade in the vat, and dye in a fresh beck with a clear solution of methyl violet, adding 1 lb. nitrate of tin.

Pansy Blue to stand milling on Cloth for Ladies' Paletôts (200 kilos.).—I. Ground in the vat; rinse, and dye with 4 kilos. iodine violet; enter cool, boil for an hour, and let it remain three hours below boiling; take through pure cold water to which 20 kilos. sulphuric acid have been added; rinse, whiz, and dry.

II. Mordant with 24 kilos. alum, 6 kilos. chromate of potash, 4 kilos. sulphuric acid, and boil for two hours; let cool in the liquid, and dye with 15 kilos. logwood and 4 kilos. soluble iodine violet; boil for ninety minutes, and let it remain in the beck for two hours longer without boiling.

Aniline Violet to bear milling (5 kilos.).—Make up a beck with half a kilo. bichloride of tin, and add clear solution of methyl violet as required. Enter the goods, and keep for forty-five minutes near 212° Fahr. without actually boiling; lift, whiz, and dry.

Pansy on Alpaca and Vicuna (10 lbs.).—Boil the yarn in bundles; let it soak for some hours, and wash in soap and soda; rinse, and enter in a beck at 212° Fahr. in which has been dissolved 1 lb. tannin, and steep four to five hours; wring, and steep for two hours in bichloride of tin at 2° B.; rinse, wring, and dye to shade in methyl violet B B B B at a hand-heat.

Green, Woollen Garments (5 kilos.).—Cleanse with soap, and rinse; boil forty-five to sixty minutes with 1 kilo. alum, a quarter kilo. argol, 130 grms. sulphuric acid, 1 kilo. fustic, and 180 grms. indigo extract.

Bluish Claret (5 kilos.).—Wash well with soap; rinse, and boil for forty-five minutes with half a kilo. alum, 130 grms. argol, and 40 grms. perchloride of tin; let cool in the liquid; rinse slightly, and dye with 280 grms. peachwood and 750 grms. archil. Instead of the peachwood, 50 grms. magenta may be used.

Bright Brown (5 kilos.).—Soap, rinse, and boil forty-five minutes with 1 kilo. prepared tartar, 1 kilo. archil, a quarter kilo. turmeric, and 1·8 kilo. extract of indigo; lift, and rinse. The shade may be modified by adding magenta.

Yellowish Brown (5 kilos.).—Boil in 180 grms. chromate of potash, 20 grms. blue vitriol, 130 grms. sulphuric acid, and 250 grms. sulphate of soda. Let cool in the liquid, take through water, and dye at a boil with 320 grms. peachwood and 1½ kilo. fustic for thirty minutes. Darken if needful with decoction of logwood.

Violet (5 kilos.).—Make up a beck with half a kilo. sulphate of magnesia and as much solution of methyl violet as needful. Enter, and raise slowly to a boil; rinse, and dry.

For dyeing woollen blue in vats—see article VATS—which serve both for woollen and silk; the operation is simply dipping or working in the vat, and then exposing to the air.

MIXED FABRICS DYED TWO COLOURS.—Mixed fabrics of cotton and woollen, as coburgs and damasks, are very common; these are either dyed all of one hue, or the cotton and woollen are dyed of different colours. This last is seldom done, except with new goods, or in cases where very light-coloured goods are wanted a dark shade, in which case a light and dark tint may be communicated. The process for doing this is very simple. As the process used for woollen will seldom produce the same colour on cotton, the two have to be dyed separately. For most colours it is necessary to dye the woollen first, and then the cotton; in a few the cotton is dyed first. In most cases the processes given will serve the purpose; as, for instance—

Green and Pink.—The woollen is first dyed a green by any of the processes described above, and then the cotton is dyed pink by the process.

Green and Crimson.—Dye the woollen by working for an hour in 2 lbs. of tartar, 4 lbs. of alum, 6 lbs. of fustic, and then add half a pint of indigo extract, wash out, and lay over night in 6 lbs. of sumach; work half an hour in red spirits made to 2° Tw.; wash, and work for an hour in 5 lbs. of peachwood at hand heat; raise with alum; wash, and finish.

Blue and Orange.—First dye the cotton a blue by the blue vat, wash, and then dye the woollen by working one hour in 2 lbs. of tartar, 8 ozs. of cochineal, 2 lbs. of fustic, and 2 pints of "double muriate" (bichloride of tin); wash from this, and dry.

In this way almost any two colours may be dyed upon cotton and woollen, although woven together, by proceeding as the receipt for the tint required on each sort of fibre; and except as in last receipt, where cotton is dyed by the blue vat, and consequently fast, the woollen is always to be dyed first. The same rule is applicable to silk and woollen. The two have to be dyed separately, although in many cases the silk becomes more imbued during the dyeing of the woollen than the cotton is.

A mixture of silk and cotton, when required of two shades, has also to be done in the same manner; but it is much more difficult, and cannot be done with all kinds of colours; it is a process, however, seldom resorted to. But the intelligent dyer will be able to dye any two tints by following the rules and receipts given.

MIXED FABRICS DYED ONE COLOUR.—Should the mixed fabrics be required all of one colour, the same double process has often to be adopted, especially when the fabrics are cotton and woollen; as, for instance,

Black on Cotton and Woollen.—The woollen is dyed first, and then, to dye the cotton, the goods are laid in sumach, and dyed, and so on for any colour of these mixed fabrics.

Brown on Cotton and Woollen by one Process.—Work the goods for two hours in catechu, then work for an hour at boiling heat with 8 ozs. of chrome and 2 ozs. of tartar; lift out, and work an hour in 2 lbs. of fustic and 8 ozs. of cudbear; wash, and dry. Should a deeper shade be required, or a tint more of the chocolate hue, add with the cudbear 4 ozs. of logwood.

Black on Silk and Woollen by one Process.—Work an hour in a solution of 8 ozs. of tartar and 8 ozs. of copperas, and wash out; work for fifteen minutes in a decoction of 4 lbs. of logwood; lift, and add 1 oz. bichromate of potash; work half an hour, and dry.

Black on Cotton, Silk, and Woollen, by one Process.—Steep for six hours in 2 lbs. of sumach, then work for an hour in a solution of 6 ozs. of tartar, 6 ozs. of sulphate of copper, and 6 ozs. of copperas; wash from this, and work half an hour in decoction of 4 lbs. of logwood; lift, and raise with 1 oz. of copperas; work ten minutes; wash, and dry.

Should a very deep black be required, add 1 lb. of bark with the logwood; all else the same.

Drabs on Cotton, Silk, and Woollen, by one Process.—Work half an hour in 8 ozs. of sulphate of iron and 4 ozs. of tartar; lift, and drain; then work for half an hour in 4 ozs. of logwood and 1 oz. of bichromate of potash; wash out, and dry.

By varying the quantity of these stuffs, or by using a little fustic or peachwood in the last bath, a great variety of shades of drab, slates, or fawns may be produced, the different fibres being equally dyed.

Black (100 lbs.).—Boil 40 lbs. logwood, 10 lbs. fustic, 20 lbs. myrobalans, and 3 lbs. red argol. Cool, enter the pieces, and boil for an hour. Lift, and add 6 lbs. copperas and 4 lbs. blue vitriol.

Boil again for an hour; lift, cool, and shade in the same liquor with 5 lbs. ammonia and 2 lbs. soda ash.

If for redying garments, take per 2 lbs.:—1 lb. logwood, one half lb. fustic, one quarter lb. sumach, 1½ oz. argol, and afterwards 2 ozs. copperas, 1½ blue vitriol, and lastly, 1½ oz. ammonia.

Navy Blue for Pieces and Rags (10 lbs.).—I. Boil with 3 ozs. argol and 3 ozs. chromate of potash. Rinse, prepare with 2 lbs. of sumach, and dye at a gentle boil with 1 lb. logwood and one quarter oz. aniline violet. Lift, and work at a hand heat in a beck of 2 lbs. logwood for half an hour. Lift, drain, and sadden in a fresh beck with one half lb. blue vitriol. Lift, and rinse well.

II. Prepare with 2 lbs. sumach; drain, take through black liquor at 2° B.; rinse, and dye at a hand-heat with 2½ ozs. methyl violet. For darker shades use stronger black liquor.

Red Brown on Mixed Goods (5 lbs.).—Clean, and wash; boil for an hour with alum 1 lb., argol 2 ozs., tin solution 1 oz., and turmeric 4 ozs. Wash, and enter in a lukewarm sumach beck (one half lb.), and steep for two hours. Lift, drain, and enter in a bath of red liquor at 16° Tw. Give a few turns, and let steep over night. In the morning air for an hour or two; wash, and enter in a cold beck of peachwood, raising the temperature slowly to 160° Fahr., but not to a boil. Lift, and finish with 2 ozs. glue and 2 ozs. starch.

Light Green for Satins with Cotton Warp (5 kilos.).—Prepare as for magenta with 1½ kilo. sumach or 300 grms. tannin; lift, whiz, and dye in a fresh beck of methyl green and a little picric acid, at 62° C. Finish as for magenta, colouring the gum with methyl green.

Magenta for Satin with Cotton Warp (5 kilos.).—Boil forty-five minutes with 1 kilo. curd soap, rinse in warm water, and stove for six hours. Pass through soda at 1° B.; rinse again, take through muriatic acid at ½° B., and rinse again. If the materials have been already cleansed and stoved these operations are needless. Mordant at a boil for one hour with one half kilo. sumach, or 100 grms. tannin. Take out and whiz. Make up a beck with 35 grms. of magenta at 93° C., and dye to shade. To finish, dissolve one quarter kilo. gum-arabic in water, and colour it with a little dissolved magenta. Take through this solution, dry, and calender.

Yellowish Mode for Mixed Pieces and Rags (10 lbs.).—Boil 1 lb. of good catechu in water, let settle, and dissolve in the clear liquid 1½ oz. of blue vitriol. Raise to a boil, and work the goods, first at that heat, and then for an hour at 62° C. Lift, drain, and make up a cold beck with one half lb. nitrate of iron. Work for an hour, drain in the centrifugal, and make up a fresh boiling beck with 1½ oz. chromate of potash. Work for fifteen minutes, rinse, and dry. For yellower tones add a little fustic and alum, and for redder, peachwood and magenta.

DYES FOR MIXED GARMENTS.—*Fast Black* (10 lbs.).—Wash well, and steep over night in the decoction of 2 lbs. myrobalans. Lift in the morning, and work for half an hour in (black) nitrate of iron at 5° B. Rinse, and take through a very weak solution of soda. Boil for ninety minutes with one quarter of a lb. chromate of potash and three quarters of a lb. red argol, and let cool in the beck. Lift, and dye with logwood and fustic as requisite.

Black (5 kilos.).—Steep with soda, rinse, and work for an hour in the warm decoction of 2½ kilos. sumach. Boil out 3 kilos. logwood and one half kilo. fustic, and make up a cold beck with the extracts. Enter the goods without rinsing, raise slowly to a boil, and keep at that heat for ninety minutes. Lift, and dissolve in the beck three quarters kilo. copperas and 375 grms. blue vitriol. Re-enter, and boil forty-five to sixty minutes, and take out. If the wool is too heavy and looks bronzed, run off half the liquor, cool down with cold water, and add 1 litre ammonia. Work the goods for another thirty minutes, lift, and rinse in cold water. If the cotton shows, when dry work afresh with 2½ kilos. myrobalans, lift, drain, &c., without rinsing, enter in a fresh beck of 2 kilos. copperas, and work for thirty minutes. Take out, and without rinsing pass into a cold beck of 16 grms. bichromate of potash. Rinse, and enter in a cold beck of 1½ kilo. logwood, and heat by degrees to 37° C.

Nicholson Blue (10 lbs.).—Boil 5 lbs. pale myrobalans, and dissolve in the clear liquor a quarter of a lb. curd soap, and steep the goods over night. In the morning wring, and dye in a boiling beck with 2½ ozs. Nicholson blue; wring, and take through lukewarm dilute sulphuric acid. Rinse, take through size or gum tragacanth water, and finish.

Dark Aniline Blue (10 lbs.).—Make a decoction of 5 lbs. sumach, strain, and steep the goods over night in the clear lukewarm liquor. Make up a beck with a solution of aniline blue. Lift the goods from the sumach beck, wring out, enter in the dye beck, and turn constantly whilst the dye is slowly raised to a boil.

A swallow-blue may be obtained by subsequently saddening the goods in a fresh beck with alum and logwood.

Sea Blue (5 kilos.).—Steep over night in the clear hot solution of 1 kilo. sumach, in which has been dissolved half a kilo. of soap. Wring out well in the morning, and dye to shade with a clear solution of 15 to 30 grms. Nicholson blue, adding half a kilo. of soda crystals. Wring, and wash. Pass through a cold beck of 130 grms. sulphuric acid, and bloom, if required, with a little methyl violet. If a sadder shade is required, take the goods through a beck of 20 to 30 grms. copperas after the sumach.

Brown on Mixed Silk and Cotton.—Boil a quarter lb. of catechu in a sufficient quantity of water, and make up a beck at 37° C. Steep the goods in the clear liquor for five hours, turning them frequently. Lift, wring out, and take through a weak chrome beck at 50° C., using half an oz. of chromate of potash to each article. Work in this bath from fifteen to thirty minutes, wash, and dry. If the cotton appears too pale it may be darkened in a decoction of logwood.

This brown may be converted into a Bismarck shade by working in a cold solution of magenta.

Chamois (10 lbs.).—Wash well with soap and rinse. Boil 2 ozs. annotta in the solution of one half oz. potash; let settle, and make up a beck with the clear liquor. Enter, heat to a boil, and keep up this heat for half an hour. Lift, and wring slightly. Raise in a beck of water at a hand heat, to which 6 ozs. sulphuric acid have been added.

Another Chamois (5 kilos.).—Boil the goods, previously cleaned, in a beck of 1 kilo. alum, one quarter kilo. young fustic, and a little magenta, for 30 minutes. Let cool in the liquor, take out, and rinse.

Green (2 lbs.).—Extract $1\frac{3}{4}$ lb. of bark at a boil, strain, and dissolve 2 ozs. alum in the clear liquid. Steep in this with frequent turning for three hours. Make up a dye beck with 3 ozs. alum in hot water and the clear solution of 2 ozs. of indigo carmine. Take up the goods, press slightly, and steep in the above bath for half an hour, turning frequently. Then raise to near a boil, and as soon as the weft and warp appear even lift, cool, rinse, dry, and finish. Avoid giving too blue a tone.

Green on Old Mixed Silks.—Boil out 100 grms. sumach in water, strain the liquid, and steep over night in the hot clear liquor. Lift the next morning, press out, and dye in a fresh cold beck of methyl green. If a yellower shade is required picric acid is added.

Magentas are prepared in an analogous manner, and also pansies; dyeing in the first case with cold solution of the best roseine, and in the latter with cold solution of methyl violet.

Bright Medium Green (10 lbs.).—Wash and rinse, and boil for forty-five minutes with 2 lbs. alum, 3 lbs. fustic, and half a lb. extract of indigo. Rinse, and work for an hour in a beck made up with 3 lbs. pale myrobalans at 87° C.; wring, and dye up to shade in a fresh cold beck with 3 ozs. aniline blue.

Another Green (5 kilos.).—After dyeing the wool or worsted, enter in a beck at 84° C., made up with half a kilo. of alum and the same weight of fustic. Work for an hour, lift, drain, and enter in a fresh beck with 1 kilo. sumach. Steep for two hours, turning frequently, wring well out, and dye up in a fresh cold beck with methyl green. Darken, if needful, by adding decoction of logwood to the last beck.

Rose (5 kilos.).—Prepare at a boil with 1 kilo. sumach; lift, make up a fresh beck with saffranin, enter, raise slowly to a boil, and cool in the beck.

Violet (5 kilos.).—Wash and steep over night in a hot beck of $1\frac{1}{2}$ kilo. sumach, or 180 grms. tannin. Lift next morning, and work for half an hour in perchloride of tin at 1° B. Make up a fresh beck with one quarter kilo. sulphate of magnesia, and add clear solution of methyl violet of the tone required. Enter the goods at a hand-heat, and raise slowly to a boil. When the wool or worsted is well dyed, allow the beck to cool, add more methyl violet, and work till the cotton is of the right shade. Rinse, and finish with gum tragacanth water.

Yellow (2 lbs.).—Boil up 2 ozs. turmeric in water, strain the liquid, and steep the goods all night. In the morning, lift, and add 2 ozs. alum. When quite dissolved, enter the goods. The addition of half an oz. muriatic acid improves the shade. If the wool has not taken the colour, heat to a boil and keep turning.

These few receipts for dyeing mixed fabrics will show the care required in such operations; nevertheless, by a little practice they all become simple, and new methods and modifications are continually being introduced.

FINISHING.—After the completion of the dyeing, properly so called, the pieces are, as a rule, saturated with an excess of uncombined colouring matters, from which they require to be freed by copious washing. This was formerly effected by suspending the goods in a clear running stream. Since in manufacturing districts the rivers are now more adapted to soil than to cleanse anything, this primitive method of washing has given place to mechanical arrangements. The pieces, on leaving the dye beck, enter a large tank of water, where they are well agitated; hence they pass between two cylinders, under a torrent of water discharged upon them from above; they next descend into a narrower tank, from which water falls from a wide pipe; they are then passed between a second pair of cylinders, still exposed to a copious shower of water.

The process of drying is conducted in various manners, according to the nature of the goods. Cloth is generally stretched out in "tenters" (extenders) in the open air, or in large sheds heated by steam-pipes. Certain colours very susceptible to light, such as safflower shades on any kind of material, are best dried in the dark, by means of a current of cold air driven over them by means of a fan. Worsted and mixed stuffs, such as coburgs, merinos, delaines, &c., are dried by passing over rollers heated by steam.

The process of finishing has of late attained unsatisfactory proportions. Goods, both white and coloured, are made to depend to a great extent for their appearance, and even for their body, not so much upon textile fibres (whether vegetable or animal), as upon a variety of dressings, finishings, and weightings, for which the wool, cotton, or silk serves mainly as a kind of framework.

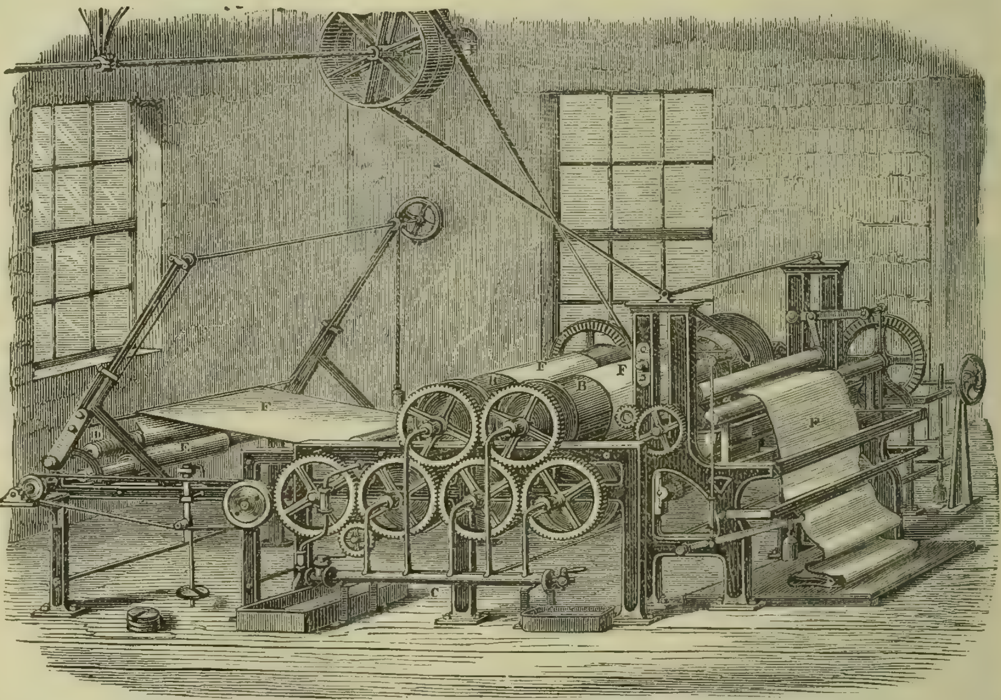
Gums, Iceland moss, starches, glue, sulphates of lime and baryta, Epsom salts, and chloride of magnesium, dexterously mixed and introduced, hide a multitude of deficiencies. These additions are made most largely to cotton goods: woollen cloths are weighted to some extent with the chloride of manganese.

Stuffs, previous to finishing, are moistened with an extremely fine shower, produced by allowing water to descend through a sieve of silk. They are then passed over the finishing machine, a French form of which is shown in Fig. 49. The machine figured is in use at the dye works of M. FRANCILLON, at

Puteaux, for muslins, poplins, and the like. A is a sheet-iron box containing the dressing; *a*, the roller which takes up the dressing and distributes it over the cloth; B B, five cylinders, heated by steam, round which the stuff passes; C is a large tube, from whence issue brass pipes to convey steam to the rollers, B; D is the guide roller to E, the receiving roller for the finished stuff; F F is the muslin on its way through the machine.

Turkey Red.—The principal use of madder is to dye cotton cloth different shades of red. This hue is known in this country and on the Continent by the name of Turkey or Adrianople red, and is one of the most durable colours known. The method of dyeing this tint—the characteristic of which consists in previously impregnating the goods with an oily or fatty substance—was first discovered in India, where the natives have been wont, from time immemorial, to steep the yarns which they intend to dye in liquids containing fatty matter—such as milk, for example. The art was first introduced into France towards the middle of the last century. In 1747, MM. Ferquet, Goudard, and d'Haristoy brought a party of Greek dyers into that country, and formed two establishments—one at Darnetal, near Rouen, and the other at Aubenas, in Languedoc. Nine months later a person named Flachat, who had long resided in the Ottoman empire, brought over workmen, with whom he formed at St. Chamont, near Lyons, a third establishment for the dyeing of Adrianople red—so called from the high celebrity then enjoyed by the productions of that city. But these foreigners could not long keep their art secret; they had soon numerous imitators; and in 1765 the French government, convinced of the value and importance of this method of dyeing, made the processes known to the public. Many establishments were formed in various parts of the country; but it appears that the only successful ones for some years were those at Rouen. From these parts the Turkey red dye gradually made its way into Alsace, Switzerland, Great Britain, and different parts of Germany. At first the cotton was only dyed in the yarn; and it was not till 1810 that the cloth itself was dyed directly of this colour at the establishment of Messrs. Kœchlin, Mulhausen, and that of L. Weber.

Fig. 49.



It is stated by the late Dr. Thomson of Glasgow and other authorities, that the first Turkey red works in Great Britain were established in that city about the end of the last century by M. Papillon. It appears, however, from a paper on the Art of Dyeing read before the Literary and Philosophical Society of Manchester by Mr. Thos. Henry, in 1786, and quoted by Mr. Baines in his History of the Cotton Manufacture, that M. Borelle, another Frenchman, introduced the art of dyeing Turkey red at Manchester, probably some years previous to its introduction at Glasgow, and that he obtained a grant from Government for the disclosure of his plans, as M. Papillon afterwards did from the commissioners and trustees for manufactures in Scotland; but the method of the latter obtained the most decided success. It was in the year 1783 that Mr. David Dale and Mr. George Macintosh engaged Papillon, who was a dyer at Rouen, to settle in Glasgow, and he there founded and carried on for many years in partnership with him a Turkey-red business. The period having expired in 1803 when the process was to be divulged, the commissioners and trustees above mentioned laid a complete account of it before the public. Since that period Turkey red dyeing has been conducted in Glasgow, and also in Lancashire, on a very extensive scale.

The following is the process given by Dr. THOMSON, and followed by the most skilful Turkey red dyers in Glasgow:—

1. The cloth is steeped in a weak alkaline lie to remove the weaver's dressing. This is technically called the *rot steep*. From 4 to 5 lbs. of caustic potassa are generally employed for every 100 lbs. of cloth. The temperature of the solution is from 100° to 120° Fahr. The cloth is kept in the steep for twenty-four hours, and then well washed.

2. From 7 to 10 lbs. of carbonate of soda are dissolved in a sufficient quantity of water to keep the cloth—always supposed to be 100 lbs.—wet. In this solution the cloth is boiled for some time.

3. It is upon the third process that the beauty of the colour depends more than on any other. Without it the dye cannot be produced on new cloth. But when old cotton cloth has been frequently washed—a cotton shirt, for example—is to be dyed, this process may be omitted altogether.

A liquor is composed of the following ingredients:—

One gallon Gallipoli oil;

One gallon and a half of soft sheep's dung;

Four gallons of a solution of carbonate of soda, of the specific gravity 1·06;

One gallon of solution of pearl ashes, of the specific gravity 1·04.

These are mixed up with a sufficient quantity of cold water to make the whole mixure amount to 22 gallons. The specific gravity of this liquor should be from 1·020 to 1·025.

This liquor has a milk-white appearance, and is in fact a kind of imperfect soap. It is put into a large wooden, open, cylindrical vessel, called the "liquor tub" and is kept constantly in motion, to prevent subsidence, by wooden levers driven round in it by machinery; it is then conveyed by tin pipes to a kind of trough, in what is called the "padding machine," where the cloth is thoroughly soaked in it. The longer the cloth is allowed to remain impregnated with this solution, the better does it take the dye. Fourteen days is the least period that this impregnation is allowed to remain.

The padding machine is similar in principle to that employed for starching, already described, and other forms of it were described in connection with the "padding style" of calico printing.

The sheep dung gives the cloth a green colour, and is found materially to assist the bleaching process, to which it is afterwards subjected. It is found to increase the rapidity of the bleaching, especially when the cloth is exposed on the grass between the different operations

4. In favourable weather the cloth impregnated with the imperfect soap of No. 3 is spread upon the grass to dry. But in rainy weather it is dried in the stove or "hot flue." This method of drying dyed and printed goods is fully described in connection with CALICO PRINTING.

5. The cloth thus dried is a second time impregnated with the oleaginous liquid of No. 3. It is then dried again.

The impregnation and drying are repeated a third time.

6. The cloth is steeped in a weak solution of pearl ash, of a specific gravity from 1·0075 to 1·01, heated to the temperature of 120°. From this liquor it is wrung out, and again dried.

7. A mixture is made of the following substances:—

One gallon Gallipoli oil,

Three gallons soda lye, of specific gravity 1·04, diluted with as much water as will make up the whole to 22 gallons. In this liquid the cloth is soaked as it was in that of No. 3.

The cloth thus impregnated is in fine weather dried on the grass, in rainy weather in the stove.

8. The process No. 7 is repeated thrice, and after each soaking the cloth is exposed for some hours on the grass, and finally dried in the stove.

9. The cloth is steeped in a mixed lye of pearl ash and soda, of the specific gravity 1·01 to 1·0125, heated to the temperature of 120°. It is allowed to drain for some hours, and then well washed; it is then dried in the stove. The object of this process is to remove any superfluous oil which might adhere to the cloth. Should any such oil be present, the succeeding process, the "galling," could not be accomplished.

10. For the galling, 18 lbs. of Aleppo galls are to be boiled for four or five hours in 25 gallons of water, till the bulk is reduced to about 20 gallons. This liquid, after straining, is strong enough to impregnate 100 lbs. of cloth with the requisite quantity of nutgalls. Of late years sumach from Sicily has been substituted for nutgalls; 33 lbs. of the former being reckoned equivalent to 18 lbs. of the latter. Sometimes a mixture of 9 lbs. of nutgalls and 16½ lbs of sumach is employed.

In this liquor, heated to 80° or 100° Fahr, the cloth is fully soaked. The sumach gives the cloth a yellow colour, which serves to improve the madder red, by rendering it more lively.

11. The next step is to fix the alumina on the cloth. This process is essential, because without it the madder dye would not remain, but would be washed off by water.

In this country alum is used by the manufacturers, but in many parts of the Continent acetate of alumina is employed. To form the alum liquor of the Turkey-red dyers, to a solution of alum of the specific gravity 1·04, as much pearl ash, soda, or chalk is added as is sufficient to precipitate the alumina contained in the alum. Through this muddy liquor, which should have a temperature of from 100° to 120° Fahr, the cloth is passed, and steeped for twelve hours. The alumina is imbibed by the cloth, and combines with its fibres.

12. The cloth thus united with alumina is stove-dried, and then washed out of the alum liquor.

13. These essential preliminary steps having been taken, the cloth is ready to receive the red dye.

From 1 to 3 lbs. of madder, reduced to the state of powder, are employed for every lb. of cloth; the quantity depending upon the shade of colour wanted The cloth is entered into the boiler while the water is cold. It is made to boil an hour, and the boiling continues for two hours. During the whole of this time the cloth is passed through the dyeing liquor by means of the wince.

For every 25 lbs. of cloth dyed 1 gallon of bullock's blood is added. This is the quantity of cloth dyed at once in a boiler. The addition of the blood is indispensable for obtaining a fine red colour. Many unsuccessful attempts have been made to leave it out. It seems probable that the colouring matter of blood is fixed on the cloth.

14. *Madder brown* by this process is fixed on the cloth as well as madder purple or madder red. This gives the cloth a brownish-red and rather disagreeable colour. But the brown tinge not being nearly so fixed as the red, it is got rid of altogether by the next process which is known by the name of the "clearing" process. The cloth is boiled for twelve or fourteen hours in a mixture of 5 lbs. soda, 8 lbs. soap. and from 16 to 18 gallons of the residual liquid of No. 9, with a sufficient quantity of water. By this seething the brown colouring matter is mostly removed, and the cloth begins to assume the fine tint which characterizes Turkey-red dyed cloth. It is still further improved by the next process.

15. 5 or 6 lbs. of soap, and from 16 to 18 ozs. of dichloride of tin, "single muriate," in crystals, are dissolved in water in a globular boiler, into which the cloth is put. The boiler is then covered with a lid which fits close, and the ebullition is conducted under the pressure of two atmospheres, or at a temperature of 250·5° Fahr. The boiler is furnished with a safety valve and a small conical pipe, the extremity of which has an opening of about three-tenths of an inch in diameter, from which there issues a constant stream of steam during the operation. The salt of tin is found materially to improve the colour. Probably the oxide of tin combines with the oleaginous acid of the soap fixed in the cloth This insoluble soap doubtless unites with the red colouring matter of the madder, and alters the shade.

16. After all these processes the cloth is spread out on the grass, and exposed to the sun for a few days, which finishes the clearing.

Such is a sketch of the Turkey red dyeing, as practised in the principal works in Glasgow Many attempts have been made to shorten these tedious processes, but hitherto without success. The impregnation with oil, or rather soap, is essential. If one, two, or three immersions be omitted, the red is inferior in proportion to these omissions. Doubtless this soap combines with and remains attached to the cloth. And the same remark applies to common soap.

Cloth bleached by means of bleaching powder does not produce a good red. Probably the fibres of the cotton wool combine with lime, or rather with sulphate of lime, which, by decomposing the oleaginous soap, prevents it from combining with the cloth. But cloth bleached by the old process—namely, boiling in lie or soap, and exposure to the action of the sun, answers perfectly. The colours would be as good without the galls as with them. But there would be considerable difficulty in sufficiently impregnating the cloth with the alum liquor without its being previously passed through the gall decoction, especially if the cloth be in the least degree greasy.

FRENCH PROCESS.—The following process is given on the authority of PERSOZ as generally practised in France:—

1. *Oiling the Goods.*—Assuming that the goods to be dyed are 1000 kilos. (2200 lbs.) of cotton, and that they have been previously well washed and scoured in a soap bath, a liquor composed of the following ingredients is employed:—1287 to 1430 lbs. of fat oil, 3300 lbs. or 330 gallons of water, holding in solution 20 to 22 lbs. of carbonate of potash.

The oil, the water, and the carbonate of potash, in these proportions, are divided into three equal parts, with which 3 parts of white liquor are formed successively as required, incorporating with the oil in small portions at a time the quantity of alkaline solution necessary to produce an emulsion. One third of the goods to be oiled is padded in the first portion of this white liquor, and after this operation the pieces are laid together in a heap in a fresh and cool place, where they are left for ten to twelve hours; they are then put to dry in an atmosphere heated to 140° Fahr.

While the drying of the first portion of goods is in progress operations are commenced on the second, which are passed into the second portion of white liquor; and when these are soaked, macerated, and put to dry, the same operations are performed with the third portion of goods in the remaining portion of white liquor. By this means the process is carried on without intermission; for while the pieces last padded are lying at rest, others are in the drying room, and others are being steeped in the liquor.

After each padding in the white bath, followed by the lying of the goods in a heap and the subsequent drying process, the different portions of goods are returned to their respective white liquors, in which they are again worked. When the bath begins to fail, either a little tepid water is added or a certain quantity of "old white liquor" proceeding from the washings; and this operation is repeated several times, according to the quantity of oil which it is desired to fix on the stuff.

The number of paddings in the white bath, which are always performed in the same manner—that is to say, followed by a period of rest and then desiccation in a heated atmosphere—is generally seven or eight. The next process is what is termed the "degraissage," or the removal of the superfluous oil, which is performed by macerating the goods twice, successively, for twenty-four hours each time, in a solution of carbonate of potash at 1·2° Tw. The liquid which is wrung or pressed out of them constitutes the "old white liquor," which is employed again in the oiling operations. The goods being carefully rinsed, are now ready to receive the galling.

Galling or Mordanting.—This operation is performed on two occasions; first, before the first maddering, and again before the last maddering. 22 lbs. of bruised gall-nuts are subjected to several boilings till well drawn; and sufficient water is added to the product to form in the whole about 66 gallons, in which 35 lbs. of alum are dissolved with the assistance of heat. This liquor is introduced hot into the padding machine, and kept at the temperature of about 160° Fahr. during the whole time that the goods are worked in the bath. This quantity of gallo-aluminous liquid is about sufficient to mordant one half of the goods under treatment; that is to say, 500 kilos., or 1100 lbs. of cotton. On taking the goods from the padding machine, they are suspended for two days in a drying-room heated to about 112° Fahr., and then passed into a hot concentrated bath of chalk. As there is a large proportion of undecomposed alum on the cloth, and the base of which only becomes adherent by the intervention of saturating substances, if the goods were unequally immersed in this bath, there would necessarily follow infiltrations and flowings, producing belts or lines which would entirely destroy the beauty of a fine red ground. Care must, therefore, be taken to avoid this. The mordant being thoroughly fixed, the goods are washed, and present a fawn-coloured appearance.

The Dyeing.—The dyeing is performed on ten pieces at a time, with proportions of madder which vary according to the breadth and length of the pieces, from 13, 15, 17, to 20 lbs. a piece. As in the preceding process, the madder is divided into two equal portions. That which is to serve for the first maddering is mixed with the quantity of water required—330 to 400 gallons—and the ten pieces are introduced into this bath, brought to a tepid state, and are kept in it three hours, progressively raising the temperature during two hours and three-quarters, till the bath arrives at a state of ebullition, which is not to be continued more than a quarter of an hour. On coming out of this bath the fabric is washed, then submitted to the action of the cleansing machines, rinsed, and dried.

Second Galling or Aluming.—After this first maddering, steep again in the gallo-aluminous preparation; dry, and pass into the chalk bath, as after the first galling.

Second Dyeing.—This dyeing is performed in the same manner as the first, but without the addition of chalk, enough of which remains in the goods.

First Clearing.—This first clearing, as well as those that follow, is performed in the close boiler, filled two-thirds with water, containing in solution—

13 lbs. of soap,
3½ lbs. carbonate of potash.

The boiling must be continued for eight hours.

Second Clearing.—This is done with—

14½ lbs. of soap,
14 ozs. dichloride of tin—"single muriate."

Third Clearing.—Same as the foregoing.

After this third clearing, which is only required for very bright reds, the goods are exposed for some time to the air; and after this exposure are worked through a bran bath, which exalts the brightness of the colour. The red is then finished.

The process which has just been described is slightly modified by some French dyers: thus, as a long experience has proved that the oil is better fixed in the stuff when the drying is not performed too rapidly, there are some who, when the season does not admit of exposing the goods to the air, heap the pieces together, after the oiling, in a drying-room heated to 95° Fahr., taking the precaution to turn them over from time to time to prevent their becoming heated to an injurious extent. Some French dyers also have introduced the use of ox-blood, employing it in the proportion of 40 lbs. to 100 lbs. of madder.

FRIES' PROCESS.—PERSOZ gives the subjoined process as one which had long been employed with success by this eminent dyer:—

The cottons to be dyed were lixiviated in lime, passed into acid at 1·2° Tw., washed in the dash-wheel, submitted to the action of a lye of carbonate of soda containing 53 lbs. of the soda salt to 880 lbs. of the cotton, and lastly, again washed and dried.

For the treatment of 100 pieces of calico of 40 yards in length, or about 4000 yards, two large wooden vessels, A, B, were used, each of 110 gallons capacity. 90 gallons of water, holding in solution 36 lbs. of carbonate of potash, were introduced into the vessel A, and into the vessel B 190 lbs. of fat oil, slightly heated if in winter, and to which the alkaline liquor of the vessel, A, was added by small portions at a time, and carefully stirring till the oil formed a perfect emulsion. The pieces were then padded in this emulsion, and if the operation was conducted with care, the quantity of white liquor formed was sufficient for the one hundred pieces. These were then put into a heap till next day, or exposed on the grass in fine weather; otherwise they were dried in a moderate heat, not exceeding 105° Fahr. On coming from the drying-room they were padded again in a second white bath, exposed on the grass in favourable weather, or if the weather was unfavourable put again into the drying-room, heated this time to 113° or 115° Fahr.

These two white baths having been given, what remained of the liquid in the vessel, B, was poured into the vessel, A, which was filled up with water proceeding from the operation for removing the superfluous oil, or, in default of that, with water holding in solution carbonate of potash marking 1·2° Tw.; in this species of white liquor the goods were worked five or six times successively, taking care to expose them on the field after each operation; they were then put into the drying-room, gradually raising the heat, but not to exceed 120° Fahr.; after the last immersion they were kept in the drying-room for eighteen to twenty hours, at a temperature of 100° to 120° Fahr.

The Degraissage.—This operation for removing the superfluous oil was performed as follows:—On withdrawing the goods from the stove they were put into a vessel and sprinkled with enough of tepid water at 90° Fahr. to wet them thoroughly; a workman with wooden shoes then tramped them well, turning them over three or four times to multiply the points of contact, and lastly wrung them, carefully collecting the lactescent water so expressed. This is termed "the water of degraissage." After this operation the goods were submitted to the action of cleansing machines, in which they were rinsed till the water came out perfectly clear. They were then dried to receive the galling or mordanting in the next process.

First Galling.—55 lbs. of nut-galls were boiled four hours in 44 gallons of water, and the decoction left to settle. The clear portion was then taken, and enough of water added to it to form 110 gallons, dissolving in this decoction—

110 lbs. of purified alum, and
8 lbs. of acetate of lead.

The goods were put into the padding machine in this gallo-aluminous decoction, used hot, but taking the precaution not to give too much pressure. When thus padded with mordant, they were exposed in a drying chamber to a moderate temperature, where they were left at least three days, and afterwards passed into a chalk bath at 90° Fahr. This last operation was performed in a tub on four pieces at a time, to which four double turns were given, employing for the first four pieces 4½ lbs. of chalk, and only 2¼ lbs. for each of the other four. Nevertheless, to prevent the accumulation of too much chalk in the bath, it ought to be renewed after passing twenty-four pieces through it. On coming out of the bath the goods are washed in the dash wheel.

First Maddering.—For eight pieces of 40 yards in length the bath contained—

70 lbs. of Palus madder,
4¼ lbs. of Sicilian sumach.

The temperature of the madder bath was regulated so as to reach 212° Fahr. in two hours and a half, and was kept at this temperature one hour, which gave for the duration of the dyeing three hours and a half. After the maddering, the goods were rinsed, carefully scoured, and dried in the air or on the grass.

Second Galling or Aluming.—In this operation the process of the first galling was exactly repeated; the mordant was the same, the only precaution to be taken was not to work the goods at too high a temperature: it should be such that the hand may be held in the solution without inconvenience. The goods were then left at rest three days; then passed into chalk, and rinsed without scouring.

Second Maddering.—This was given like the first, and followed by a rinsing in running water.

First Clearing or Brightening.—In a covered boiler, containing 330 gallons of water, the following ingredients were dissolved:—

17½ lbs. of carbonate of potash,
4½ lbs. of white soap.

Ten pieces, oiled and maddered, were put into this liquid, kept at boil five hours, and on being taken out, rinsed in running water.

Second Brightening.—Still using the same covered boiler, the same number of pieces were put into a similar quantity of water with these ingredients—

17½ lbs. of soap,
3½ lbs. of carbonate of potash,
1 lb. of dichloride of tin (single muriate).

This liquid was brought to ebullition, and kept in that state five or six hours.

Third Brightening.—In the same quantity of water were put only—

9 lbs. of soap,
14 ozs. of carbonate of potash,
14 ozs. of dichloride of tin (single muriate).

After five hours ebullition, the goods were taken out of the covered boiler, scoured with the washing machines, and exposed on the grass eight or ten days, turning them over three or four times daily.

When the cloth which had passed through these different operations was intended to be sent into the market with a plain ground, it was passed into a water slightly acidulated with hydrochloric acid, and then rinsed.

When the goods to be brightened were sparingly oiled, they received only two brightenings—the first with 9 lbs. of soap and 5½ lbs. of carbonate of potash; the second, with 10 lbs. of soap, and 14 ozs. of single muriate (dichloride of tin).

Such was the course followed and the proportions of ingredients used for a first portion of the goods; for the remaining portions the quantity of oil was diminished, and also that of the carbonate of potash, in consequence of using the waters of "degraissage" from the preceding operations. The quantities employed were therefore—

For the second portion, ...35½ lbs. of oil,
For the third portion, ...33 " "
For the fourth portion, ...28½ " "

added to the water of the vessel A, 1½ oz. carbonate of potash for each pound of oil introduced into the vessel B.

The two preceding processes for dyeing Turkey red differ only in the degree of temperature at which the goods are dried, in the quantity of acetate of lead added to the alum to give it a greater tendency to fix itself on the stuff, and lastly, in the addition of sumach to the madder bath. These differences, however trifling they may appear, often lead in practice to results, the importance of which entitles them to consideration.

Swiss Turkey Red Process.—Switzerland has long enjoyed celebrity for its Turkey reds. Their success, says Persoz, may be attributed to the great reduction which has been effected by the dyers of that country in the quantity of oil and weight of madder employed. The quantity of oil formerly used was at least equal to half the weight of the cotton, whereas it is now reduced to a fourth; and the madder used, from being double the weight of the cotton, is now reduced by many dyers to the same weight—that is to say, 100 lbs. of madder, instead of 200 lbs. as formerly, are now taken for dyeing 100 lbs. of cotton; and yet the results leave nothing to be desired.

There is not anything essentially new in the process followed in Switzerland; its excellence consists only in the application of several scattered data, the uniting of which in the same process conduces to results of the most satisfactory character. It is to the same circumstance that Elberfeld owes the superiority of its products in this department of dyeing.

Oiling.—In the process commonly followed in Switzerland, the white baths are given at a temperature of 80° to 85° Fahr., adding to the ingredients, already stated as usual in the French process, cow dung in a state of fermentation.

For a portion consisting of 200 kilos., or 440 lbs., of cotton, the following ingredients are employed:—

29½ lbs. of fat oil,
55 gallons of carbonate of potash, in solution, at 39·2° Tw.,
13½ gallons of cow dung, fermented, and brought into a pulpy state with a little cow urine.

The cow dung is mixed with 50½ gallons of water heated to 98° or 100° Fahr., the oil is added, and the whole is formed into an emulsion by introducing, in successive portions, 4½ gallons of carbonate of potash in solution, at 39·2° Tw. The temperature of the liquid being then brought to the desired point, the goods are padded in the usual manner. They are then introduced into a wooden trough, in which they are left to themselves for twelve or eighteen hours to set up a fermentation, which is often carried to such an extent that it is not a rare occurrence to see myriads of small worms developed in that short period. They are then dried in the open air, and exposed during eight or ten hours in a stove heated to 145° Fahr.

After this first bath, they receive a second, a third, and a fourth, always fresh prepared, adding to the residue of each of them the proportions indicated above, so that, after these four oilings, the 440 lbs. of cotton have consumed—

117½ lbs. of oil,
220 gallons of carbonate solution,
54½ gallons of cow dung;

and after each bath the goods are exposed, first to the air, and then in the stove heated to 145° Fahr.

These four oilings are followed by other four, performed in the same manner, but in tepid water, holding in suspension the residues of the four original white baths, and the "old liquors" from the "degraissage." After each of these immersions they are dried in the open air and stoved, as after each passage through the white bath, but at lower temperatures—namely, at 140° Fahr. after the fifth and sixth baths, and about 132° after the seventh and eighth, with which this operation is concluded.

The next process is the "degraissage" or "unoiling," by the method indicated in the last process. The "old liquor" is collected during this operation, and the goods are then cleaned by the dash-wheel, from which they are taken out to be wrung, and then dried in the stove at the temperature of 120° Fahr.

Galling.—The galling is also performed in two operations; for the first, in which no alum is used, the following ingredients are boiled for one hour in 44 gallons of water:—

16¾ lbs. gall-nuts,
14 lbs. Sicilian sumach.

To allow this decoction to clear, it is left to itself for twenty-four hours after passing it through the sieve; then decanted and heated to 110° Fahr. The goods are then padded with this liquor, dried in the open air, and afterwards stoved at the temperature of 120° Fahr.

The second galling is performed exactly in the same manner as the first, except that the sumach is kept back and alum added.

In 48½ gallons of water heated to 115° dissolve—

47 lbs. of purified alum, saturated with
77 lbs. of carbonate of potash, in solution, at 39·2° Tw.

After passing the goods through this bath, they are wrung or pressed out, and left in a heap during six hours; they are then put into the stove—heated to 80° Fahr.—to be dried, without a current of air; they are next "ventilated" for three days, and afterwards passed through the stove heated to 120° Fahr. Then, as the alum is only partly saturated, they are passed through a chalk steep raised to the temperature of 120°, using 5⅕ lbs. of chalk for 40 lbs. of cloth. When rinsed and dried after coming out of this bath, the goods are ready for dyeing.

The Dyeing.—This is performed in one operation, taking for 44 lbs. of the fabric from

44 to 66 lbs. Palus madder,
6 lbs. sumach,
3·74 gallons ox blood.

The temperature of the bath is progressively raised during two hours and a half, and the boiling is kept up half an hour; the pieces are then rinsed, and submitted to two brightenings, which they receive in the covered boiler, where they are boiled six hours, namely:—

For the first operation, with 11 lbs. of soap, 66 lbs. of carbonate of potash, and 44 lbs. of dichloride of tin (stannous chloride).

For the second brightening, with 11 lbs. of soap, 44 lbs. of dichloride of tin, and 286 of nitric acid.

After these brightenings, the goods are exposed on the grass for two or three days, and then passed into a boiling bran bath.

This process is essentially distinguished from the preceding ones, inasmuch as all the operations tend to provoke a fermentation among the different substances which are found in presence of each other, and to determine the metamorphosis of the fatty body. While recognising the necessity of reaching a certain degree of heat, it evinces, at the same time, a full appreciation of the importance of giving due scope to the action of the air. This action is exerted so much the better on the cotton in proportion as the latter contains a certain quantity of water, whilst a too rapid drying withdraws it from the influence of the agent which is called to perform the principal part in the reaction. It is doubtless for this reason that the dryings in the stove-chamber are always preceded by exposures in the open air.

Turkey Red, Nitric Acid Process.—In the process which has just been detailed a small portion of nitric acid is used in the brightening; but in that which follows it enters in considerable quantity into the oiling. The process has been used with good results by Gastard, to whom dyers are indebted for the direct application of the colouring matter of madder. The following are the details of this method, as communicated by that gentleman to Persoz:—

Preparation of the Goods.—After leaving the goods for a period of twenty-four hours in water heated to 70° or 80° Fahr., they are worked through it, and then boiled four hours in water containing 66 to 70 gallons of old white liquor; they are left in the same boiler till next day, when they are again well sodden, rinsed twice, and dried.

For sixty pieces of cotton weighing 233 to 240 lbs., the white bath is composed as follows:—

7·7 lbs. of fat oil.
2·6 gals. of sheep or cow dung.

Oiling.—With the substances above mentioned, incorporate a solution of carbonate of potash at 5·4° Tw., till a perfect emulsion is produced, sufficient to impregnate the whole of the fabric. Pad the pieces in this emulsion, expose them to the air in the sun, if the weather permit; if not, hang them up to dry. When the desiccation is nearly finished, introduce for four or five hours into the drying stove, heated to 150° or 160° Fahr.; on coming out of the stove they are twice worked through water, acidulated with nitric acid at 1·2° Tw., and then dried in the air, but not now in the hot stove, where they would infallibly be burned. They afterwards receive—

1. A second white bath like the first, followed by exposure to the air and in the hot stove;

2. A second passage through nitric acid at 1·2° Tw., followed by drying in the open air;

3. A third white bath similar to the first, and followed in like manner by an exposure to the air and in the hot stove;

4. A third passage through nitric acid at 1·8° Tw., followed by drying in the open air;

5. A fourth white bath similar to the first, followed by exposure to the air, and stoving at the temperature of 150° to 160° Fahr.;

6. A fourth and last treatment with acid, to which succeeds a drying in the open air.

For the last two oilings the dung may be omitted.

Degraissage.—After all these operations, the goods are passed into a solution of carbonate of potash at 6° Tw.; they are then wrung out, collecting the old white bath, dried in the air, left to steep in water for two hours, and, lastly, rinsed and dried twice over.

Galling.—The galling is also given in two operations: the first, in a perfectly clear decoction of 36 lbs. of Sicily sumach; the second, in a decoction of nut-galls.

In both operations the liquor is used hot, and the two are followed by drying.

First Aluming.—In the quantity of water required to impregnate these 240 lbs. of cotton, dissolve—

26·8 lbs. of alum, and add
1·65 lbs. of acetate of lead,
4·4 gals. of solution of carbonate potash at 5·4° Tw.;

pad the goods in the liquor, which should be used cold, and after it has cleared by settling, it ought to indicate 5·4° Tw. The goods are then laid in a heap, and left in that state twelve to fifteen hours, after which they are dried, and then put to steep in water four hours; finally, they are rinsed twice in running water.

First Maddering.—To madder the sixth part of the quantity of goods indicated, or about ten pieces, use—

37 lbs. of madder,
2·2 to 2·6 gals. of ox blood,
4·4 to 6·7 lbs. of sumach.

The dyeing is effected in three hours, gradually raising the liquid to the boiling point. On coming out of this bath the goods are washed, scoured, and dried.

Second Aluming.—This aluming is performed in the same manner as the first, except that, when the goods are dried, they are passed at the temperature of 120° Fahr. into a bath of cow dung impregnated with chalk, and then rinsed.

Second Maddering.—Same as the first.

First Brightening.—For thirty pieces, or 116 to 120 lbs. of the stuff under operation, pour into a boiler of suitable capacity, half filled with water, 11 to 13 lbs. of carbonate of potash, 66 to 70 gallons of old white liquor; boil four or five hours, and leave the goods in the boiler till next day; then take them out to be rinsed and beaten; and, lastly, spread them on the grass, where they are left exposed four or five days according as the colour develops.

Second Brightening.—Pour into the clearing boiler, along with the quantity of water required, a decoction of 2·2 lbs. of bran; when the liquid is in full ebullition add to it a solution of 16·5 lbs. Marseilles white soap, and then, by small portions at a time and stirring well, a solution of 1 lb. of dichloride of tin in 1 gallon of water, acidulated with half a lb. of hydrochloric acid, and 1½ to 2 ozs. of nitric acid, according as it is desired to give to the fabric a more or less scarlet tint. The goods, previously wetted, are then introduced into the boiler, in which they are boiled for an hour, and left in it till next day.

Persoz remarks, that if chalk does not appear prominently among the agents employed in this process, this may be attributed to the circumstance that the waters employed by M Gastard were essentially calcareous. He calls attention, at the same time, to the fact that the consumption of oil is greatly reduced by this method, since 30 lbs. of that substance suffice for the oiling of 240 lbs. of cotton; and what is remarkable, he affirms that, notwithstanding the small quantity of fatty matter employed, he found the results fit to be compared with the finest samples produced by the ordinary methods.

VIOLETS ON THE TURKEY RED SYSTEM.—By mordanting the oiled goods with an iron, instead of an aluminous mordant, violets of great beauty and peculiar lustre are obtained. For this colour it seems to be essential to employ sheep dung, and to pad the cloth with an iron mordant at its maximum of oxidation; the nitro-sulphate is used for this purpose. PERSOZ affirms, as the result of his own experience, that very fine violets may be obtained by mordanting the oiled goods in a solution of ferric sulphate, obtained from the calcination of ferrous sulphate, and marking 4° Tw., mixed with 7 to 8 per cent. of chloride of ammonium. On coming out of this bath, the goods are dried, then passed into another bath of arseniate of lime and potash, as in fixing ordinary mordants.

The Turkey-red process is far too important to be passed over without some attempt to explain the action of the different ingredients employed, which result in producing the most beautiful and permanent of dyes.

First, with reference to the "oiling," PERSOZ remarks that to oil the goods for this purpose, it is not sufficient to cover them with some fatty body, since experience proves that a spot of oil or grease, which is not modified in some manner, acts as a resist or reserve on the part of the stuff which it covers, and prevents the mordants of iron or alumina from adhering to it. The nature of this body must therefore be modified by the aid of alkalies or alkaline compounds, under the threefold influence of water, heat, and air. Nevertheless, there is not in this case a simple saponification, as some have maintained; for if so, it would be sufficient to use soaps having for their base olive or common oil, to impregnate the fabric with these, and then to set the fatty acids at liberty, in order to bring the goods to a state capable of being dyed a rose colour in a madder bath. But this is not the case, for the oiling operation never succeeds better than when carbonate or bicarbonate of potash or soda is used, the saponifying action of which substances at the common temperature is not to be compared with that of caustic alkalies. The cause must therefore be sought in another direction. The oil and the bicarbonates are doubless the principal substances of this operation; but the former must not be a drying oil—it must be of that kind which is termed in commerce "fat oil," and use must be made of certain matters, such as sheep or cow dung, which it has not been found possible to dispense with. Gallipoli oil is generally used in this country; that employed on the Continent is of the same nature, and is termed in France "huile tournante" from its tendency to become rancid, and from the circumstance that, when mixed with a solution of carbonate of potash or soda, it immediately produces a milky emulsion, coloured slightly yellow. These oils are obtained from olives which, before being pressed, are submitted to the action of hot water, and are consequently strongly charged with extractive matters.

After being padded with the white liquor, consisting of a mixture of the fat oil, bicarbonate of soda or potash, and excrementitious matter, the goods are dried, as has been stated, either by exposure to the sun or in the hot stove. During this drying process the fatty body experiences a modification which renders it insoluble in weak alkalies, and acquires in a very high degree the property of strongly adhering to the fabric; but as this modification begins at the surface of the goods, and the external portion of each coating of the white liquor is easily detached, not having entered into combination with the stuff, the operation of passing through the white bath is repeated till the fabric is sufficiently impregnated with the oil. The number of passages through the white liquor is regulated both by the season and the temperature of the stove in which the goods are dried, as well as by the nature of the oil employed. Formerly, eight to fourteen baths were given; the number is now much reduced.

The heat of the sun and of the weather exercises a very great influence on the goods when dried in the air. In autumn, in winter, and in spring, much more difficulty is experienced than during the summer season in modifying and fixing the fatty substance. When the goods are exposed in a drying chamber, the effects of the artificial heat are not less marked, and if the proper temperature is not attained, important differences are observed in the intensity of the shades produced.

The modification which the fatty substance undergoes when it is submitted, in contact with the fabric, to the threefold influence of the air, of heat, of the alkaline carbonates—the products into which it is metamorphosed; in a word, the rationale of this mysterious operation—have not been satisfactorily explained. WEISSBERGER, one of PERSOZ's pupils, found that the oiled stuffs, which give up their modified fatty substance to oil of turpentine, yield it also to acetone; and by availing himself of this property, and afterwards evaporating the acetone in the water bath, he found as the residue a viscous liquid of a fatty nature, which separated itself into two strata, the one solid, the other liquid, and capable of being kept a long time in the same state. The modified fatty substance having been extracted by the acetone from the cloth which had passed through the white bath, WEISSBERGER ascertained that, in proportion as this substance was abstracted, the cloth lost its power of attracting and combining with the madder dye. Desirous of knowing whether this viscous liquid still possessed the essential property of the fatty body by which it was generated, he saponified it with powerful bases, and finding no trace of glycerine in the products of the saponification, he was forced to conclude that this substance had disappeared. Lastly, he showed, and PERSOZ himself repeated and verified the experiment several times, that it was only necessary to apply on a stuff a suitable quantity of this modified fatty body, so abstracted by acetone, to obtain with the madder the deepest and purest shades; and from his experiments on this subject PERSOZ concludes, that so soon as this fatty body can be directly prepared, the use of the aluminous mordants may be dispensed with. This observation, which seems at first rather extraordinary, is supported by another made by Chevreul on a particular "Turkey red" which he analyzed, and from which he could only extract a very small quantity of alumina, although a large proportion of that substance had been used in the dyeing process. If the glycerine disappears in this operation, it is by undergoing an oxidation and a transformation, the former being produced by the united action of the air and the conditions of temperature at which the oiling is performed; the latter by the use of nitrogenized substances indispensable for putting the organic matter in motion. Persoz thinks that to these substances must, doubtless, be attributed in great part the necessity of using excrementitious matters; he conceives also that the phosphates which exist in the latter in considerable quantity may exercise an important influence.

The object of the alkaline washing, which follows the white baths, is to remove that portion of the fatty body which has not undergone the requisite modification, and also that portion which, although modified, is not in a state of adherence to the fabric; for if these portions of the organic mordant were not removed, the inorganic mordant next applied would not be fixed on the goods in an equal and uniform manner, in consequence of the unmodified fatty substance acting the part of a resist.

It is generally acknowledged that in the process of oiling, the fatty body is better modified and fixed on the stuff in proportion as the latter is longer exposed to the air with the humid oily preparation upon it, but under protection from the rain and the too powerful action of the solar rays, and also in proportion as the stoving is conducted at the proper temperature. It appears best to impregnate the fibre only at its surface, for otherwise the shade becomes too deep, and it is difficult to pass it through the brightening process without diminishing the liveliness of the tint. By cutting a piece of cloth which has been dyed the finest red, it will be seen that the interior of the fibre is white, which proves that the oil and the aluminous mordant penetrate only imperfectly into the centre. This application of the colour to the surface of the stuff gives a peculiar lustre to the shade, which the colourless or slightly coloured interior of the cloth naturally renders clearer and more transparent.

When the goods have been oiled, great care must be taken to prevent the slow or spontaneous combustion of the fatty body with which the stuff is charged: in the former case the charge is always more or less injured; in the latter, the establishment is in danger of being set on fire.

The slow combustion, as well as the spontaneous, proceeds from either too much oil in the stuff, or from too little carbonate of potash having been employed to saturate it. The first is determined by the exposure of the goods in too powerful sun-heat, or by the heat which is developed from their lying too long in a heap; the second is produced by the action of the oxygen on the free oil which covers the goods when in the stove. Turkey red dyers who employed, in other respects with success, drying oils from seeds, were compelled to give up the use of such oils in consequence of the accidents of this kind to which they led.

When the goods have been perfectly scoured after the oiling operations, which is known by wringing them at one end, and observing whether the water comes out perfectly clear, they are covered evenly over with inorganic mordant. Alum or acetate of alumina is used for red mordant, nitro-sulphate of iron for violet mordant; but the preparations do not perform what is required of them in the same conditions, for the affinity of the modified fatty bodies for alumina, however great it may be, is yet insufficient to determine the total decomposition of the alum, and the complete fixation of its base on the stuff, for which purpose it requires to be saturated. Hence, while some dyers are satisfied with padding their goods in acetate of aluminium, to give them the proportion of that base necessary for the fixation of the colouring matters, those who use only alum—the general practice in this country—must necessarily interpose other bodies to favour the adherence of the alumina to the stuff. They have, therefore, recourse to galling, perhaps without being aware of its use, although it is in fact a preliminary operation to which all goods were formerly submitted that required to be mordanted. It follows that there are two methods of mordanting, one of which consists in padding the goods purely and simply with acetate of aluminium, the other in impregnating them with a decoction of nut-gall or sumach, an operation properly termed "galling," and which is most generally confounded with that of aluming, by previously making an astringent decoction which should mark from 11° to 12° Tw., and in which the alum is dissolved. Daniel Kœchlin, who used acetate of aluminium, arrived at the conviction that the interposition of the nut-gall has no influence on the shade of the red; its only advantage, he believed, was in giving the colour more solidity, especially when the goods have to pass into a solution of bleaching powder. When padded with the gallo-aluminous solution, they are dried and passed into a chalk bath, to saturate the alum and render it cubical, so as to be capable of yielding up its base to the stuff.

The next process is the "dyeing" or "maddering," which is not performed in precisely the same manner in all establishments. In some it is done at one operation, in others at two; the first dyeing is termed in France the "retirage," and the second "bouillissage." Again, the proportions of madder required vary between a quantity equal to the weight of cotton employed and twice that quantity, along with a certain proportion of chalk. It is impossible to obtain fine rose tints which have no tendency to pass to a violet shade, without the intervention of this last-named substance. The effect of lime has long been known to give a peculiar beauty and durability to colours.

Independently of the chalk, a certain quantity of sumach is often mixed with the red to economize the madder. It results, in fact, from the experiments of J. M. Haussmann, that an addition of sumach and nut gall to the madder bath contributes to the development of a much larger quantity of colouring matter. But Edouard Schwartz, who has corroborated this advantage so far as regards the amount of colour produced, is convinced that the reds dyed in this manner are infinitely less fixed, and consequently ill fitted for those styles which required to be passed through the chloride of lime liquor.

Besides the sumach, bullocks' blood, in the proportion of one-fourth of the madder employed, is sometimes added to the madder bath; or a certain quantity of Cologne glue, which is mixed with the sumach in equal parts, and amounts to the fourth part of the madder.

In some dye houses the maddering is performed over an open fire, in others the vessels are heated by steam; but as for this kind of dyeing the temperature must be kept at the boiling point, and there is a large condensation of water, some dyers have recourse to a convoluted pipe for circulating the steam to heat the bath.

The "brightening" constitutes the last series of operations, and these will be considered first with reference to the agents employed, and secondly as regards the apparatus required.

The brightening or clearing of Turkey red differs essentially from that of ordinary reds in this respect, namely, that for common reds the first operations tend chiefly to fix the fatty body of the soap, and to render it a constituent part of the lake which is formed at the surface of the stuff, to give it in this way all the stability and brightness possible; whereas, in the brightening of Turkey red, the fabric being saturated with fatty matter, the effect to be produced consists, first, in removing the excess of that fatty matter, and secondly, in substituting for the alumina (the base of the red lake), a certain quantity of oxide of tin, which modifies its shade and gives it that fiery tint which is characteristic of Turkey red, and is so opposite to that of the common red, which inclines to amaranth.

The substances which serve for the brightening are carbonate of potash, soap, and stannous chloride. Generally the soap and carbonate only are used for the first brightening, and the dichloride of tin is introduced in those that follow. After the first operation the soap and chloride of tin are alone employed. The part performed by these substances is easily understood: the carbonate of potash and soap effect the solution of the fatty body in excess, and dissolve at the same time a pretty large proportion of the colouring matter which is found remaining in the bath. As regards the dichloride of tin, it undergoes decomposition, and oxide of tin is produced, which displaces a portion of aluminous oxide, takes its place, becomes oxidized, and converts the red into a fiery shade, by reason of the orange tint which the compounds of tin assume in the madder bath.

When, after the clearing operations, the red assumes a rose shade, this is a proof that the cotton has not been sufficiently saturated with oil, or that the quality of this oil has not been suitable, or that the white baths have been mismanaged, or, lastly, that the dryings have not been performed at the temperature required for the modification of the fatty body.

With reference to the apparatus used in the brightening processes, the liquor is heated in a covered boiler of about 220 to 260 gallons capacity, containing, with the requisite quantity of water and soap, any amount up to 700 yards of cotton goods, oiled and maddered; they are left to boil under a certain pressure from twelve to eighteen hours, and are brightened a second, or even a third time, according to the degree of intensity which it is desired that the red should possess.

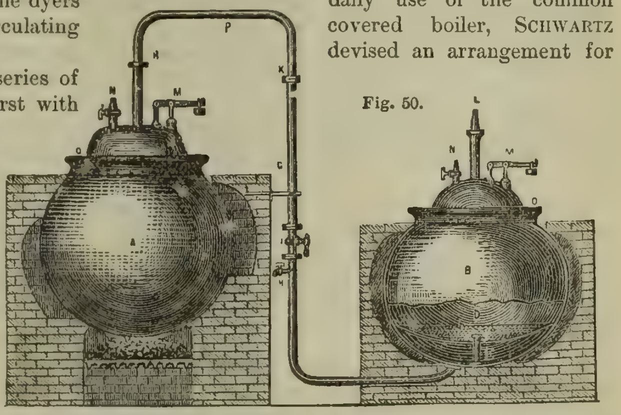


Fig. 50.

To avoid the loss of steam which results from the daily use of the common covered boiler, Schwartz devised an arrangement for economising the waste steam. This arrangement is shown in Fig. 50. Contiguous to the ordinary boiler, A, is placed another, B, which communicates with the former by means of a jointed tube, P, fitted with a stopcock, I, by which the steam disengaged from the boiler, A, passes into the boiler, B, under the false copper bottom, D. This false bottom is perforated like a colander, and rests on the support, E; on this bottom the goods in this boiler are placed. Both boilers are furnished with safety valves, M, M, with discharge-cocks for the steam, N, N, and with stopcocks below for discharging the fluid contents.

O is a flange, which, by arresting the water of condensation that runs down the lid, prevents it from falling on the heated sides of the boilers. The object of the stopcock, H, is to second the operation of the safety valve, and to enable the attendant to watch the progress of the operation. When steam escapes on the opening of the stopcock all is right; but when water comes out, this is a proof that a valve which is placed at R is not working, and that the steam must make a passage for itself by the safety valve.

It is easy to work these boilers. When the quantity of water required for one operation has been pumped into the boiler, A, and brought to ebullition, the agents employed in the brightening process, and the quantity of goods to be subjected to their action, are introduced; the lid is then fixed on, with the pipe, P, attached to it, carrying at the joining, R, a valve which opens upward. The stopcock, I, is then opened, and the steam which passes into the boiler, B, brings the liquid in that boiler to ebullition in the space of three hours. The latter is then charged in the same manner as the first boiler, covered over, and the steam allowed to enter during seven hours. The goods in the generating vessel thus receive a boiling of ten hours; those in the other only seven hours. When the boiler, A, ceases to give out steam, the valve of the boiler, B, is shut, that no steam may be lost. The latter preserves so much heat that the goods may be left in it two hours longer, at the end of which period it has still a certain pressure. And as it is the custom to give a shorter time to the goods at the second and third brightening, the boiler, A, is specially employed for the first operations, which are kept up longer, and the boiler, B, for what is properly called the "rosing."

Old copper vessels may be employed for the boilers, A, which do not receive the direct action of the fire. To prevent the condensation of the steam, especially in cold weather, it is necessary to surround the boiler, B, with a casing of some non-conducting substance, such as felt, &c.

During the process of brightening great care must be taken that the tube and safety-valve do not get out of order; negligence in these matters has often produced heavy losses, and sometimes even the death of the workmen engaged in conducting the operation.

Such is a general review of the process of dyeing Turkey red, as conducted in almost all the establishments in which it is carried on, both on the Continent and in this country. Another process was proposed by J. M. HAUSSMANN, which differs in some important particulars from any of the common methods. It consisted in dissolving 1 part alum in 2 parts warm water, and while in a state of ebullition introducing into this liquor enough of concentrated caustic potash lye to precipitate and redissolve the alumina of the alum. By cooling and allowing to settle, a great part of the sulphate of potash was deposited, and the clear liquor being decanted off, he added, by small portions at a time, to 33 parts of this solution of alumina and potash 1 part of linseed oil, thereby forming an emulsion with which the goods were impregnated. The cotton thus prepared was dried under shelter from the rain in summer, and in winter in a hot chamber; after twenty-four hours they were rinsed and again dried; then they were padded in the alkaline emulsion a second time, quickly dried in the air, and so on till the stuff had received the number of emulsions required. HAUSSMANN said that two impregnations of the alkaline solution of alumina mixed with linseed oil sufficed for obtaining a fine red; but by continuing to impregnate the goods a second and even a fourth time under the same conditions as the first, the colours were extremely brilliant.

By this process he oiled and mordanted his cottons at one operation, and had only then to proceed with the dyeing, which was performed in this case also with the addition of a quantity of chalk equal to one-sixth of the weight of the madder, and using thirty or forty times that weight of water. The dyeing was performed differently from the usual manner. He brought the bath gradually during the space of an hour to such a temperature as just admitted of the hand being held in it without inconvenience; he then left the cotton in it two hours longer, which gave a duration of three hours to the operation. After the dyeing, the stuff, being thoroughly washed and scoured, was passed through a bran bath, adding to it soap and carbonate of potassa, when it was desired that the goods should have a crimson-rose shade.

OILED ROSE GROUNDS.—Besides the red and violet grounds obtained by the preceding processes, rose grounds are also given to oiled stuffs. For this purpose, after oiling the goods as equally as possible, and in the same way as for reds, suppressing sometimes one or two of the oilings, and then subjecting the goods to the usual "degraissage" process, two methods are followed. Some dyers then pass them into a very weak aluminous mordant, scour, and dye in madder in the usual way; others, who by this method obtain weaker but much purer shades, put them directly into the boiler in which they brighten the goods for red shades. The colouring matter that has been detached from the latter is found sufficient to saturate the organic mordant, and to give it the desired tint. For pale colours no process can be better; for if the cloth be saturated with oil, the quantity of aluminous mordant employed will always be too great, however weak it may be, and the shade will always be too deep. Now, to degrade it would be to destroy its lustre, while, if the oiling be diminished, the tints will return more or less to ordinary reds, and will not stand the brightenings which are indispensable to bring them to the natural tone of the Turkey red.

DYNAMITE. See NITRO-GLYCERINE.

ELECTRO-METALLURGY. — *Galvano-plastique*, French; *galvano-plastic*, German.—The art of working in metals by means of electricity. This is the literal meaning of the word at the head of the article, and it suits the purpose better than either the French or German equivalent, for both of these synonyms imply moulding into form, whereas that is only one of the many developments of the art. The only portion of the subject to which "galvano-plastic" can apply is electrotypy, and it does not perfectly apply to that, for plasticity implies mouldability into form by pressure, in which the ultimate figure to be attained is arrived at by a gradual and approximative process; in electrotypy, on the contrary, the figure is obtained in a comparatively short time and perfectly, the main portion of the duration of the operation being devoted to thickening the metal that constitutes the product; again, the plastic art is an original work, but electrotypy is only capable of copying works of art already wrought by other means.

The word "electro-metallurgy" was originally used by ALFRED SMEE, in his classical work on the subject. Another word, more expressive than galvano-plastic, is "electro-deposition;" this title, however, only covers electrotypy and electro-coating metals, and leaves electro-etching and the electro-reduction of metals from their ores out of the category. For the purposes of this article, working in metals, or with metals, by means of electricity, comprises electro-coating metals, electrotypy, electro-etching, electro-reduction of metals, and other operations.

GENERAL VIEW OF THE METHOD OF WORKING.—The fundamental principle upon which the practice of this art depends is, that if an electric current be passed through the aqueous solution of a metallic salt, that surface by means of which the current departs from the solution will receive a coating of the metal in solution. The second principle, that acts contemporaneously with the first, is that the surface by means of which the current enters the solution is dissolved in the solution. These two statements presuppose that the plate of entrance, called the anode, as well as the plate by which the current departs, called the cathode, are conductors of the electric current; they also imply that the anode can be made to dissolve in the solution by the action of the current. When these conditions exist, when the anode is of the same metal as that in solution, and when the anode and cathode expose the same area in the liquid, or nearly so, the solution may be so made that it keeps in nearly the same condition as before it was submitted to the action of the current; that is to say, in a given time the solution of the anode on the one hand, and the deposition of metal on the cathode on the other hand, may be made about the same in weight.

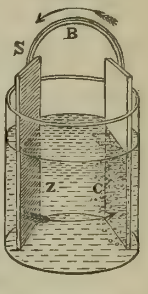
Obviously, to do any given kind of work, say to electro-silver a German silver spoon, the electric current must first be provided. This can be done in several ways, but the simplest method is by the galvanic battery.

A single galvanic arrangement, or "cell," as it is technically termed, may be simply made by soldering to the extremities of a copper wire or strip two plates, namely, a zinc plate to one extremity, and a copper plate to the other extremity. If these plates be brought parallel to each other, and immersed in a weak solution of sulphuric acid, an electric current will be established in the wire, its direction being from the end that is joined to the copper, towards the end that is joined to the zinc. In this view, the solution of the zinc by the acid may be said to liberate the electric force from it, whence it proceeds through the liquid to the copper plate, and back again to the zinc through the connecting wire.

The diagrams, Figs. 1 and 2, will serve to illustrate the action of the current of a galvanic cell.

In Fig. 1, Z represents the zinc plate, and C the copper plate of the galvanic arrangement; these plates are placed in the acid with which the containing vessel is charged, and have their upper ends connected by means of the conducting strip of copper, S. During the entirety of the conductor, S, the zinc plate, Z, will be dissolved, and the electricity thereby evolved will pass across the exciting liquid to the copper plate, C, thence along the conductor, S, back again to the zinc plate, Z, as shown by the arrows; thus the circuit of electric force which is necessary to the existence of a current is established.

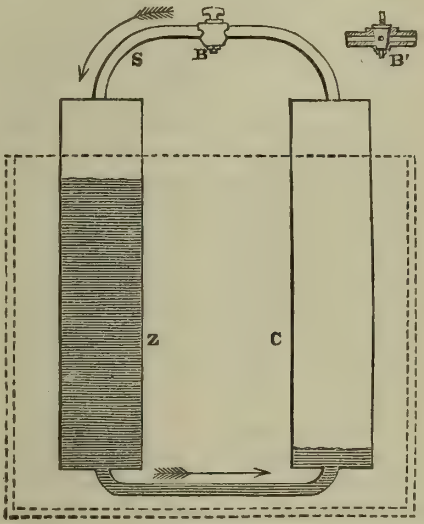
Fig. 1.



The flow of electricity along a conductor may be compared to the flow of water through a tube. To establish a flow in a tube that joins two reservoirs of water, it is sufficient to raise the reservoir from which the flow is to take place; the flow will be from the higher reservoir to the lower one, until the upper reservoir is completely emptied.

The analogous action in this hydraulic comparison is set forth in Fig. 2. Z represents a closed cistern, nearly full of water, and C an empty or nearly empty cistern also closed. These similar cisterns are connected underneath by means of a tube as shown, and at the top by another tube; the former tube is full of water, so as to present the case of an inverted syphon, when taken in connection with the two cisterns; the latter tube is an air tube. When the top or cock, B, is turned full on, the air in the respective cisterns can be exchanged, and a current of water is established in the lower tube, also one of air in the upper tube, as shown by the arrows, for the water in Z seeks to descend until the tube, C, is filled to the same height. When, as at B′, the tap is turned off, no interchange of air can take place, the circuit is destroyed, and the water in Z cannot descend, neither can the water in C rise.

Fig. 2.



So it is with the typical galvanic cell in Fig. 1. Whilst the strip, S, remains intact, and has a good metallic connection with the plates Z and C, the solution of the zinc plate by the acid causes the efflux of electric force from the zinc plate into the liquid and into the copper plate, thence the current proceeds in an uninterrupted manner across the strip to the zinc plate, whence, by continuous action of the acid, it again comes away from the zinc plate, and so produces a continuous flow, in a definite direction of electric power, until the zinc plate is dissolved. The full cistern is analogous to the zinc plate, the lower tube to the amount of acid which has access to the plates, and the empty cistern to the copper plate. The air tube corresponds to the conducting strip. If the electric conduction in the strip, S, be interrupted by cutting the metal through (at B for instance), the circuit is destroyed and the electric current ceases to flow. By means of this analogy not only is the flow or non-flow of the electric current realized, but it furnishes a never-failing method of remembering the direction of an electric current as furnished by a galvanic arrangement, together with certain other data, as will hereinafter more fully appear.

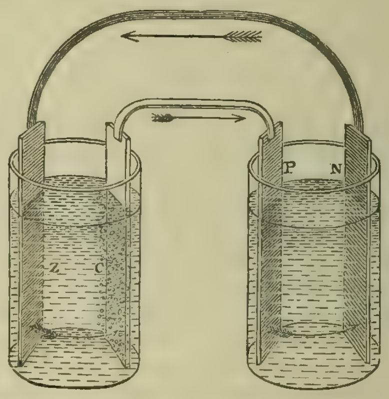
To construct a practicable galvanic cell, and thus to verify the results obtained from the arrangement shown in Fig. 1, the following points must be duly attended to:—The strip or wire must not be a mere shred or fine thread, but it must be of the same sectional area at all parts of its length, and proportioned to the amount of electric current that the plates can furnish. It should be long enough for subsequent operations. The strip or wire is soldered to the plates, that it may be connected with them by a truly metallic junction; for an electric current can only traverse with facility a metallic way or road: any rust, oxide, or other non-metallic substance, opposes the free flow of the current. The copper plate should be brightened by means of emery cloth, and the zinc plate should be amalgamated or coated with mercury. The amalgamation may be effected by thoroughly cleansing the plate from grease, immersing it in a solution composed of 1 part of sulphuric acid (by measure) to 15 parts of water, and then rubbing some mercury over the wet plate with a flannel.

The liquid in the cell may be made by adding very gradually, and with stirring, 1 part (by measure) of sulphuric acid (oil of vitriol) to 20 parts of water. If the sulphuric acid were added hastily to the water, the heat evolved might crack the vessel, which, for easy observation, should be of glass. These arrangements being satisfactorily completed, and the plates being immersed in the acid solution, bubbles of gas are seen to be copiously evolved from the surface of the copper plate. The strip may now be cut about midway between its junctions with the plates. Instantly the evolution of bubbles of gas from the copper plate ceases, showing that an action at work during the passage of an electric current has stopped, and that the current is no longer in existence.

To further test the existence of an electric current, and to exemplify the two fundamental principles enunciated at the beginning of this section, the free ends of the cut wire may be soldered to two other equal-sized clean copper plates, each to its own plate. If these plates be placed in another vessel similar to that containing the galvanic arrangement, and if a strong solution of sulphate of copper (blue vitriol) be poured therein, as shown in Fig. 3, the electro-deposition of beautiful pink copper will immediately commence upon the plate connected with the zinc, and the plate connected with the copper of the galvanic cell will be seen to become dull and oxidized. Moreover, if after some hours each plate be weighed, the anode (P) will be found to have lost weight, and the cathode (N) to have gained weight. The anode is called the positive or dissolving plate, and the cathode the negative or receiving plate.

The single galvanic arrangement just described has been called a *cell*. When several cells are joined together by their conductors in such a way that the zinc of the first cell has its wire free, and that the copper of this cell is connected with the zinc of the second cell, the copper of the second cell with the zinc of the next, and so on, the arrangement is called a galvanic battery, and the cells are said to be joined in series.* The area of the zinc must be proportioned to the area of the article or articles to be coated. A number of cells is employed when the solution does not conduct electricity freely.

Fig. 3.



The arrangement shown in Fig. 1, and adopted in Fig. 3, is known as Wollaston's cell; it is described further on with details that make it applicable to a large scale.

To return to our typical example of the German-silver spoon that is to be electro-coated with silver.

A source of electricity is first provided, say a galvanic battery of the kind just described, the effective area of whose zinc plate in each cell is at least one-sixth of the area of the spoon to be coated, and consisting of three cells arranged in series; then a solution is made, containing cyanide of potassium and silver, and silver plates to serve as anodes are placed therein.

Before being submitted to the action of the depositing vat, the spoon must be perfectly clean, and in such a state that adhesion of the deposited metal is not a matter of doubt, but of certainty. This is best accomplished by first boiling it in an alkaline lye, then washing with abundance of water, dipping into dilute nitric acid, washing. dipping into a solution of nitrate of mercury, washing, and finally placing in the plating solution. The wire to convey the electric current to it may be attached after the dipping into the dilute nitric acid. The free extremity of the wire being connected by a metallic connection with the conductor from the zinc plate of the battery, the spoon may be allowed to remain in the solution until the required thickness of metal is deposited. This is ascertained by weighing the article before and after deposition. The spoon may remain in the depositing solution, constantly in contact with the conductor, as explained above, for about six or seven hours; at the end of which time, if every part of the operation has been properly performed, the article will be found to be coated with silver of a chalky whiteness to the extent of 1 oz. or 1½ ozs. to every square foot of surface, or the thickness of ordinary writing paper. On being taken out of the solution, the spoon may be well washed in running water, then immersed in boiling water, and dried by being buried in hot sawdust. The chalky whiteness is then removed by scratch-brushing the article, that is, submitting it to the rubbing action of rotating brushes of fine brass wire and stale beer. The brushes are mounted in the chuck of a scratch-brush lathe, and their action gives the appearance to the spoon of bright metallic silver.

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* Some workers call this method of joining the cells "connection for intensity."

SOLUTIONS FOR ELECTRO-DEPOSITING METALS.—From the General View of the Method of Working in electro-metallurgy already given, it will be seen that to deposit one metal upon another certain arrangements are common to all deposits, such as a means of obtaining electric power, methods of preparation, chiefly of producing a perfectly clean surface to the article, and finishing the article after immersion in the depositing vessel; these points are modified to suit each application of the art of electro-deposition, but the principal agent is the solution employed to precipitate the metal. The method of preparing each solution will now be described under the head of the metal to be deposited.

Copper.—Solution No. 1. The normal solution for electrotyping, and for depositing upon certain metals, is composed of:—

Sulphate of copper,	1 lb. avoirdupois.
Sulphuric acid,	1 lb. "
Water,	1 gal.

Sulphate of copper, as obtained in commerce, often contains a considerable amount of iron salts.

To test for the presence of iron, make a dilute solution of the salt, and add strong liquid ammonia to it; the light blue precipitate at first formed ought to dissolve entirely, forming a purple-blue solution. If, on the further addition of ammonia, any precipitate remains on standing, it is iron in the form of hydrated oxide. In this case the salt may be crushed very fine, and exposed to the air for some time in a flat dish that has a sheet of paper or other cover suspended over it at a little distance to keep off dust. This powder may be dissolved in water in the above proportions, and the solution allowed to stand until the oxide of iron has all fallen to the bottom. The supernatant liquid, which is clear, may then be drawn off by means of a syphon, and the lower portion, which is thick and muddy, may be filtered. The sulphuric acid should be entirely free from nitric acid; it may now be added gradually. The whole quantity of liquid should form about a gallon. According to this proportion any number of gallons of liquid may be prepared, and every gallon will contain about 4 ozs. of copper. This solution is intended to be used when a separate source of electricity is connected with a depositing cell, as shown in Fig. 3.

Solution No. 2. This, like solution No. 1, is an acid solution, and is used for similar purposes. Its composition is:—

Sulphate of copper,	2 lbs. avoirdupois.
Sulphate of zinc,	2 ozs. "
Water,	1 gal.

As sulphate of copper is soluble in four times its weight of water at 60° Fahr., the 2 lbs. of cupric salt may be dissolved in 8 lbs. of water, and the remaining 2 lbs. of water, or about that weight, added thereto, so as to make up the whole solution to a gallon when it is to be used. Generally, and it is true in this case, the solution of a salt is facilitated by powdering it, by warmth, and by suspension in the upper part of the solvent; the latter may be accomplished by placing the crystals in a canvas bag which is supported at the top of the liquid. The crystals of sulphate of zinc may be allowed to dissolve in the solution after the rest of it is made. This solution contains about 8 ozs. of copper per gallon, and it is used principally for electrotyping purposes by means of "the single cell process."

Solution No. 3. This solution is alkaline, and is used for coating articles of iron and zinc; it contains:—

Cyanide of potassium,	2 lbs.
Cyanide of copper,	3 ozs.
Water,	1 gal.

According to one method, the cyanide of potassium may be dissolved in the water, and the cyanide of copper may be added gradually to the solution; it will be found to dissolve entirely, and to leave sufficient free cyanide of potassium to dissolve the anode when under electrical influence. The solution is of a light yellow colour, and contains about 2 ozs. of copper per gallon.

The cyanide of potassium is obtained commercially in the form of white cakes or lumps; these are never pure cyanide, but any samples containing less than 40 per cent. real cyanide ($KCN = KCy$) should be rejected. The impurities consist of carbonate and sulphate of potash, chloride of potassium, cyanate of potash, ferrocyanide of potassium, and silica. This salt is very soluble, 20 parts by weight dissolving in 23 parts of water at 60° Fahr. It should be preserved from air and moisture in a well stopped jar, otherwise a part of it will decompose into ammoniacal compounds.

The cyanide of copper may be obtained as a yellowish green powder from the manufacturing chemist, and it should be of recent make. This material, however, is used to the greatest advantage while in a wet state, after washing and filtering from the solution in which it is precipitated. It is best obtained* by adding a dilute solution of cyanide of potassium gradually to a dilute solution of sulphate of copper as long as any precipitate falls, each solution being cold. No more cyanide should be added than is necessary, as the precipitate dissolves in the precipitant. During the precipitation great care should be taken not to inhale the gas which is evolved, which is very poisonous, and large operations should be conducted in a free current of air. When the precipitation is finished, the precipitate should be washed in a great many waters, until the wash water gives no precipitate with chloride of barium: the precipitate is allowed to subside after each washing, the water poured off, the vessel again filled, the precipitate stirred, and so on, until the operation is finished. About 9 ozs. of sulphate of copper will be required to yield the above-mentioned 3 ozs. of cyanide of copper. The cyanide of copper as practically produced no doubt contains impurities; it is more soluble in the wet than in the dry state.

This electro-depositing solution may be used cold, but it is preferable to heat it.

Solution No. 4. The making of this solution depends upon a principle not yet alluded to, but which will now be explained. If the depositing cell in Fig. 3 were charged with sulphuric acid only, of the strength 1 part oil of vitriol to 8 parts of water, and if, instead of the anode and cathode being equal in area, the anode were of considerable size and the cathode as small as would suffice to carry off the electric current, say a simple wire, the anode would dissolve in the solution much more rapidly than the metal would precipitate on the cathode, and the result would be that the solution would be charged with metal after a few hours constant action of the electric current. Although a very pure solution would be procured by this method, it is not necessary to employ it to obtain simply an acid solution of sulphate of copper, for the pure salt can be bought very cheaply, and the manipulation necessary for its solution is neither troublesome nor tedious. It is quite the opposite, however, with the solution of copper in cyanide of potassium, and the mere precipitation of the copper salt to dissolve in the cyanide requires some chemical aptitude.

To carry out this principle in making the alkaline solution of copper required to deposit upon iron and zinc, a solution is first taken (called the "solvent solution") composed of—

Cyanide of potassium,................	2 lbs.
Water,..............................	1 gal.

If a copper anode of about the area of a square foot be immersed in the lower part of this solution, and a small plate or wire be placed at or near the surface of the solution as a cathode, the anode will dissolve rapidly, and gas will be freely evolved from the cathode, the latter becoming coated, as the process progresses, with copper in a thread-like or wiry form. In a few hours from 1½ to 2 ozs. of copper will have entered the liquid and combined with it; the solution is then fit to be used. The electric power may be from six to twelve cells of the arrangement shown in Fig. 3, or the same number of SMEE'S cells, or three or four GROVE'S cells, or equivalent power from any other source, and the solution may be heated towards the end of the process. To ascertain the amount of copper in the solution, the anode and cathode should be accurately weighed before and after the operation, giving a certain difference in each case. The loss of weight of the anode, less the increase of the cathode, is the amount in solution. The electrolytic action which has taken place during the making of the solution may probably be represented by the formula—

$$2(KCy) + 3Cu + 2(H_2O) = Cu_3Cy_2 + 2(KHO) + H_2,$$

showing that there is an excess of potash in the resulting solution. Finally, the solution should be tested by electrodes of equal size, and an electromotive power equal to three cells of the arrangement shown in Fig. 3. This method of making the solution may be called the electrolytic method.

Silver.—Solution No. 1. The solution generally used for electro-plating consists of:—

Cyanide of potassium,................	¼ lb. †
Cyanide of silver,....................	1¼ ozs.
Water,..............................	1 gal.

The cyanide of potassium, in the form of white cakes or lumps, is dissolved in the water and allowed to settle; it is then filtered. The cyanide of silver, a white powder, is then gradually added to the alkaline cyanide solution in the above proportion; it will dissolve on stirring, and the result is the electro-plating solution desired. It contains 1 oz. of silver to the gallon.

The cyanide of potassium should be of good quality, containing not less than 70 per cent. real cyanide. The cyanide of silver is precipitated from the nitrate by cyanide of potassium, added in just sufficient quantity for the purpose and no more, and the precipitate is washed. This precipitate need not be dried if it is for immediate use. If it be desired to make the cyanide of silver from the silver itself, 1·12 ozs. of strong nitric acid will dissolve 1 oz. of silver, and the cyanide will be completely precipitated therefrom by the addition of about 0·95 ozs. of cyanide of potassium of the quality mentioned above. The depositing room should be maintained at a temperature of from 60° to 65° Fahr.

Solution No. 2. This is the solution of silver which is most easily prepared; it is also the cheapest, and there is neither time nor labour spent in preparing the silver salt for solution in the cyanide solution. The method employed to make the solution is the same as that above described for copper as the electrolytic method.

The materials employed are:—

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* Compt. Rend. xxxvi. 1099.—Dufau.

† This solution is said to be most successfully in use in Clerkenwell.

Cyanide of potassium,	½ lb.
Water,	1 gal.

This solution is placed in a large vessel, and a similar solution is placed in a flat porous vessel, which is supported in the larger vessel, so that the liquid is the same height in each vessel. In the porous vessel is put a small and clean piece of iron, and in the outer vessel a large and thick sheet of pure silver, the iron being so fixed that the conductor in contact with it does not enter the solution, and the silver being supported entirely in the liquid by means of thick silver wires. When these details are properly arranged, the silver plate and the iron plate are so connected with the source of electric power that the electric current proceeds from the silver to the iron. The size of the silver plate may be half a square foot, and the electric power employed may be equivalent to six Smee's cells, each with an effective area of 18 square inches. In a few hours the silver plate will have lost an ounce of metal; the deposition of metal on the cathode is prevented by the use of the porous vessel. The liquid in the porous vessel may contain some silver; this may be ascertained by the addition thereto of muriatic acid. Although there is free caustic potash in this solution, which by contact with the air becomes carbonate of potash, and although the resulting solution is not quite so conductive of electricity as solution No. 1, it is a very good solution in practice, and is said to be less likely to deposit non-adherent metal, or in technical terms metal "that will strip," than many others.

Gold.—Solution No. 1. The usual electro-gilding solution contains:—

Cyanide of potassium,	1 lb.
Cyanide of gold,	1·132 oz.
Water,	1 gal.

The cyanide of potassium is dissolved in the water (which should be distilled); the solution is allowed to settle, and then filtered. The cyanide of gold, a lemon-yellow crystalline powder, is then dissolved in the cyanide of potassium solution. This solution contains 1 oz. of gold to the gallon of depositing solution.

The cyanide of potassium for electro-gilding purposes is sold commercially under the name of "gold cyanide;" it should contain not less than 80 per cent. of real cyanide. Cyanide of gold is prepared by heating auro-cyanide of potassium with nitric or hydrochloric acid.

The solution is used hot, from 130° to 150° Fahr.

Solution No. 2. The electrolytic process of preparing the gold solution gives a cheap solution readily made; the solvent solution used is:—

Cyanide of potassium,	1 lb.
Water,	1 gal.

The arrangement with the flat porous cell and the iron cathode, as set forth in the description of solution No. 2 for silver, may be used in this case. The size of the gold plate, however, may be one quarter of a square foot, and the effective area of each cell 9 square inches; four Smee's cells, arranged in series, will charge the liquid with gold in about an hour, the solution being kept at a temperature of 150° Fahr.

As this operation proceeds quickly, and as gold is valuable, the process should be watched, and the anode weighed from time to time to ascertain the amount of metal in solution. Finally, the condition of the solution may be tested by connecting the conducting wire from the zinc of the battery with a bright copper plate, and using it as a cathode, reducing the effective area of the anode accordingly; if the deposit be reguline and of a good colour, the solution is finished.

In all operations with gold solutions, it will be worth while to save the wash waters, and to deposit the gold therefrom, by the addition of a solution of protosulphate of iron thereto. The liquid should be made distinctly acid by means of hydrochloric acid, and should contain no free nitric acid. The precipitate which falls is collected, washed, dried, and fused with borax and nitrate of potash. A button of impure gold will be found at the bottom of the crucible.

Brass.—Solution No. 1. For some time, in the early days of the art, considerable interest was attached to electro-depositing alloys, and more especially to depositing brass. There are many solutions for the purpose, most of them defective, and incapable of depositing a coating of metal of any great thickness, containing uniform proportions of copper and zinc throughout. One of the principal solutions is the following; like other brass solutions, it is alkaline, and is capable of coating iron and zinc; the ingredients and their numerical proportions by weight are:—

Cyanide of potassium,	12 parts.*
Carbonate of potash,	610 "
Sulphate of zinc,	48 "
Chloride of copper,	25 "
Nitrate of ammonia,	305 "
Water,	5000 "

The cyanide of potassium is dissolved in 120 parts of water. The other salts (excepting the nitrate of ammonia) are dissolved in the remainder of the water by heating the mixture to from 144° to 172° Fahr. When these are perfectly in solution the nitrate of ammonia is added; and the liquid must be undisturbed for twenty hours, at the end of which time the cyanide solution is mixed with it. When the whole mixture has cleared by standing, the supernatant liquid is drawn off for use. This solution contains 0·300 oz. of copper per gallon and 0·349 oz. of zinc per gallon. A temperature of 77° Fahr. is used to work this solution.

Solution No. 2. This solution is made by the electrolytic process. The solvent solution is composed of:—

Cyanide of potassium,	1 lb. †
Sesqui-carbonate of ammonia,	1 "
Water,	1 gal.

When the above materials are completely dissolved,

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[*] See Specification of Patent, No. 11,878 (old law), filed by Charles de la Salzede, and dated September 30, 1847.

[†] See Specification of Patent, No. 1032, filed by Timothy Morris and William Johnson, and dated December 11, 1852.

the solution is charged with brass by means of a large brass anode and a cathode only just of sufficient size to carry the electric current. The anode should be four or five times the effective area of the zinc plates in each cell of the battery employed, and a power equivalent to from six to twelve Smee's cells may be advantageously employed. As the charging proceeds, the solution may be heated up to 150° Fahr. This solution may be charged with the alloy until from half an oz. to 2 ozs. of metal are dissolved. If, upon trial, the deposited brass be too pale, cyanide of potassium should be added to the liquid; if it be too red, sesqui-carbonate of ammonia may be supplied. Generally speaking, at low temperatures the brass is of light colour, and as the heat rises the deposit becomes redder. We have found in practice that the power of the electric current influences the colour of the deposit. To keep the solution in working order it should not be worked at a temperature less than 150° Fahr., and it requires a large anode.

Bronze.—A solution that will deposit an alloy of copper and tin consists of the same ingredients and the same proportions as those used in No. 1 Brass solution, except that 25 parts of chloride of tin are substituted for the sulphate of zinc. Therefore it contains:—

Cyanide of potassium, ...	12 parts. [*]
Carbonate of potash, ...	610 "
Chloride of tin, ...	25 "
Chloride of copper, ...	25 "
Nitrate of ammonia, ...	305 "
Water, ...	5000 "

The method of mixing is similar to that used in making No. 1 Brass solution. A bronze anode is used to work this solution. It contains 0·300 oz. of copper per gallon, and 0·363 oz. of tin per gallon.

German Silver.—This alloy contains nickel, zinc, and copper. A solution for electro-depositing German silver is made by the electrolytic process, and with a solvent solution similar to that used in No. 2 Brass solution. Its constitution is therefore—

Cyanide of potassium, ...	1 lb. [†]
Sesqui-carbonate of ammonia, ...	1 "
Water, ...	1 gal.

This solution is charged by means of a large German silver anode and a small bright cathode, until, upon testing, a deposit of good colour is obtained. The addition of sesqui-carbonate of ammonia brings down the zinc more freely, and that of cyanide of potassium brings down the copper in greater quantity.

Iron.—Solution No. 1. The electro-deposition of iron is useful to protect engraved copper plates, or copper electrotypes, so as to enable them to give a large number of impressions; it has also been used for electrotypy. The following solution deposits iron upon copper or brass, and the coating has a silver colour:—

Protosulphate of iron, ...	1 lb.
Water, slightly acidulated with sulphuric acid, ...	1 gal.

Protosulphate of iron is in crystals of a light green colour; in solution, if exposed to the air, it deposits a basic salt of iron, unless it is slightly acid. The solution contains about 3¼ ozs. to the gallon.

This solution may be used in a more concentrated form, namely, 2 lbs. of crystallized salt to the gallon.

Solution No. 2. The chemicals necessary for the formation of this solution are:—

Sulphate of iron in solution,[‡]
Carbonate of ammonia in solution,
Sulphuric acid in solution.

The carbonate of ammonia is added to the sulphate of iron, thus precipitating the iron as carbonate, which in the presence of air becomes an oxide. The precipitate is dissolved by the sulphuric acid, avoiding an excess. The resulting solution is used as highly concentrated as can be; it is inclined to get acid during the depositing process, as the cathode has more metal deposited upon it than is dissolved from the anode. This may be prevented by conjoining a copper plate with the iron anode.

Solution No. 3. This solution consists of a double sulphate of iron and magnesia, of specific gravity 1·155.[§] It should be neutral, and gives iron of a good quality, that may be of considerable thickness.

Nickel.—Lately this metal has been used to protect iron work from rust. The scabbards of swords, household utensils, and other like articles, are now successfully coated or plated with this metal. Nickel has also been used to protect the silvered surface of mirrors. The solution used is composed of:—

The double sulphate of nickel and ammonium,
Water.

The amount of water used is such as to have 2 ozs. of nickel to the gallon in solution.

Platinum.—It is exceedingly difficult to obtain a reguline deposit of this metal; it is said, however, that the following solution will accomplish it:—

Bichloride of platinum, ...	169·7 parts.
Chloride of sodium, ...	58·5 "
Water.	

The platinum salt and the common salt are to be dissolved in the water. The difficulty in obtaining reguline metal arises from the tendency of the platinum to be deposited as a black powder.

Tin.—A form of tin coating has lately been proposed for architectural castings in iron. The metal is difficult to deposit, but the following solution is said to answer well:—

Pyrophosphate of potash or soda, ...	11 ozs. [‖]
Protochloride of tin, ...	4½ "
Water, ...	17½ lbs.

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[*] See Specification of Patent, No. 11,878 (old law), filed by Charles de la Salzede, and dated September 30, 1847.

[†] See Specification of Patent, No. 1032, filed by Timothy Morris and William Johnson, and dated December 11, 1852.

[‡] See *Chemical News*, vol. xxviii. p. 119, 1873—Klein's Process.

[§] *Chemical News*, vol. xxxi. p. 137—Klein's Process, worked by W. Chandler Roberts, F.R.S.

[‖] See Specification of Patent, No. 13,020 (old law), filed by Alfred Guillaume Roseleur, and dated March 23, 1850.

The pyrophosphate is first dissolved in the water, then the protochloride is added. The pyrophosphate of soda may be formed by heating to redness diphosphate of soda. This solution contains rather more than 1¼ oz. of tin per gallon.

Zinc.—Owing to the coating of iron with zinc by immersion in the molten metal, improperly called "galvanizing" the iron, being a cheap and ready process, the electro-coat of this metal has not received much attention. A solution which may be used for depositing upon iron contains:—

Sulphate of zinc, ...	2 lbs.
Water, ...	1 gal.

The sulphate of zinc may be crystallized from a spent battery liquid—say SMEE'S. Care must be taken that the solution is not acid; and in order to prevent this, carbonate of soda should be added to it until a precipitate appears, but no longer. This precaution is more especially requisite when iron is to be coated. Chemically pure zinc may be electro-deposited from this solution. The solution contains about 7¼ ozs. of zinc to the gallon.

Palladium.—The following solution has been used to fix daguerreotype pictures by the electro-deposition of a thin coat of palladium. The method is said to give them a finer tone than the usual plan by means of gold. The solution contains:—

Cyanide of potassium,
Cyanide of palladium,
Water.

The cyanide of palladium, as a precipitate, is dissolved in the solution of cyanide of potassium to saturation, and a little free cyanide is added.

Cadmium.—This metal has been proposed for coating iron and other metallic surfaces, as it is a white metal not prone to oxidate in the air, and not very soluble in dilute sulphuric or hydrochloric acids. The solution is composed of:—

Cyanide of potassium,[*]
Carbonate of cadmium,
Water.

A solution of cyanide of potassium is used to dissolve the carbonate of cadmium, then one-tenth more of the cyanide solution is added to form free cyanide. The solution is made up so as to contain 6 Troy ozs. of metal to the gallon. Heat is used to deposit cadmium, namely, 100° Fahr.

Aluminium.—The following solution will coat articles of copper, brass, or German silver, with aluminium. The materials necessary for preparing the solution are:—

Sulphuric acid,[†]
Water,
Pipe clay (silicate of alumina, more or less pure).

Half an oz. of pipe clay is taken to every pint of water; the clay is rubbed with the water until the two are perfectly mixed; the acid, in equal measure, is then added, and the mixture is boiled for one hour in a covered glass vessel. When the liquid has settled a porous vessel is immersed in the hot supernatant liquid. The porous vessel is previously charged with a mixture, by measure, of 1 part of sulphuric acid to 10 parts of water. An amalgamated zinc plate in the porous cell forms the anode of the arrangement. By this means the aluminium is deposited on the article to be coated in a reguline form.

Silicium.—The metal silicium is the base of which flint or silica is the oxide; it may be electro-deposited by means of the following materials:—

Hydrofluoric acid (by measure),[‡]	¾ oz.
Hydrochloric acid, ...	¼ "
Precipitated silica, or fine white sand, ..	50 grains.

These ingredients are to be boiled together for a few minutes, until no more silica is dissolved. The solution thus obtained, upon being used in the same manner as the clay solution in the deposition of aluminium, yields a fine white deposit of metallic silicium.

Antimony.—The solution recommended for depositing antimony is made by the electrolytic method. The solvent solution is hydrochloric acid.[§]

A current from several cells, connected in series, is passed through this acid by means of a large anode of antimony; the solution is nearly colourless.

Bismuth.—The solution which is preferred contains:—

Nitrate of bismuth,
Dilute nitric acid.

The nitrate is dissolved in the acid. The solution may be made to yield reguline metal of a faint pinkish tint.

Cobalt.—This reddish-white metal has been electro-deposited from an alkaline solution of its chloride.[‖]

Lead.—The materials and proportions used to electro-deposit this metal are:—

Lead in the metallic form, ...	6 parts.[¶]
Caustic potash, ...	60 "
Water, ...	1000 "

The caustic potash and the water form a solvent solution, and this is charged with the above-mentioned proportion of lead by the electrolytic process.

Tungsten.—To electro-deposit tungsten the materials employed are:—

Tungstic acid.[**]
Carbonate of soda solution (density 24° BEAUMÉ).
Carbonate of ammonia in solution.

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[*] See Specification of Patent, No. 12,526 (old law), filed by Thomas Henry Russell and John Steven Woolrich, and dated March 19, 1849.

[†] *Philosophical Magazine*, vol. vii. pp. 227, 228—George Gore.

[‡] See American *Polytechnic Journal*, vol. iv. pp. 357—359; also *Philosophical Magazine*, vol. vii. pp. 227, 228—George Gore.

[§] *Philosophical Magazine*, vol. ix. pp. 73, 74; and Philosophical Transactions, 1858, pp. 185–198; 1859, pp. 797–808; 1862, pp. 323–331—George Gore.

[‖] See *Chemical News*, vol. vi. p. 126, Becquerel and Becquerel, 1862.

[¶] See Specification of Patent, No. 103, filed by Charles Beslay, and dated January 12, 1859.

[**] See Specification of Patent, No. 1183. filed by Claude Joseph Edme Junot, and dated December 28, 1852.

The metallic acid is dissolved by boiling in the carbonate, the acid being gradually added until the solution is completely saturated. The liquid is removed from the fire, filtered, and diluted with distilled water until it marks a density of 8° BEAUMÉ; the liquid is again boiled, and 3 per cent. of carbonate of ammonia in solution is added thereto.

Molybdenum.—The materials employed are—

Molybdic acid,*
Carbonate of soda solution (density 24° BEAUME),
Carbonate of ammonia in solution.

The materials are treated in a manner exactly similar to that described for tungsten. Each solution is used at a temperature of 40° C.

In the case of tungsten, molybdenum, and similar rare metals, a platinum (and therefore indestructible) anode is used, and a bag containing the metallic salt, hung in the liquid, supplies it with metal to make up for the loss by deposition on the cathode.

Chromium.—A solution for depositing chromium is formed by means of—

Chloride of soda and ammonia,	1 kilo. †
Metallic chromium,	100 grms.
Distilled water,	10 litres.

The metal is dissolved in the solution of the salt. The strength of the solution is kept up by a bag of the metallic salt, and a temperature of 40° C. is employed to work it.

Titanium.—The materials employed to form a solution for depositing titanium are :—

Metallic titanium,	100 grms. ‡
Sulphuric acid, sufficient to dissolve the titanium.	
Sulphate of soda and ammonia,	1 kilo.
Distilled water,	10 litres.

The titanium is dissolved in sulphuric acid, and the solution evaporated to dryness. The double sulphate of soda and ammonia is dissolved in the distilled water, and the titanium salt is dissolved therein. This solution is worked in the same manner as the chromium solution.

Thallium.—The metal § is readily obtained in the metallic state by transmitting an electric current through a solution of its sulphate. Platinum electrodes are used.

Some solutions that are described here refer to metals that have no extended use, as metals, at present; but it has happened, and notably in electric science, that the toy of the past age is the practical apparatus of the present.

ELECTRIC POWER SUITABLE FOR DEPOSITING METALS. — *Galvanic Batteries.* — In the General View of the Method of Working in electro-metallurgy the action of a galvanic battery has been described. Every galvanic arrangement consists, at least, of three essential parts or elements—namely, the positive metal or dissolving plate, the exciting liquid, and the negative or receiving plate. Some galvanic batteries have two liquids, separated from each other by a porous vessel or diaphragm—one liquid to act on the positive plate (generally of amalgamated zinc), and the other to prevent the generation of hydrogen gas at the negative plate. The porous vessel or diaphragm also provides against the transference of the solution that contains the zinc to the negative plate. Single-fluid batteries demand our first attention, then double-fluid batteries.

Copper—Zinc Battery.—Each cell consists of a sheet of zinc, mounted in a top frame, together with a copper plate on each side. This combination is immersed in a solution composed of 1 part of sulphuric acid and 20 parts of water (by measure). The two copper plates are connected together by means of a conducting strip or wire of copper, fixed thereto by means of binding screws, and the wire is continued a sufficient length to connect it by a metallic connection with the dissolving plate in the depositing vat. The zinc plate is connected by means of a similar binding screw and conducting wire to the articles that are to receive the deposit. The three plates are supported vertically in the liquid. They should be secured at a small distance only from each other (say 1 inch apart in large apparatus) and should be nearly parallel, but rather closer at the bottom than the top. A good way of fixing the plates in large batteries (say having zinc plates 6 feet square) is to place them in grooves made in the rectangular trough that contains the plates. The trough may be of wood, with a lining of pitch, and it should be deeper than the plates to allow of free circulation of the liquid beneath them. The amount of acid liquid in the cells, to work any considerable time without renewal of liquid, should be 2 gallons to every effective square foot of zinc. The specific gravity of the battery liquid, as soon as it has cooled, after mixing at 60° Fahr., is 11·54° Tw., or 1·0577 times the weight of its volume of water. As soon as it gets, by use, to the specific gravity 1·36 (72° Tw.), or as soon as it shows a disposition to crystallize, it is spent, and may be evaporated to obtain therefrom crystals of sulphate of zinc. A fresh charge of acid liquid is then supplied to the cells. To prevent the solution of the zinc plates unless the work of deposition is going on, they are coated with pure mercury (or amalgamated), as set forth in the General View of the Method of Working. This is best accomplished on a large scale by selecting a zinc plate fresh from the rolling mills, and placing it in a stoneware pan of sufficient size to allow the plate to lie flat in it. The pan contains enough acid liquid (1 part of sulphuric acid to 10 parts of water, by measure) to completely cover the plate when it is horizontal. The pan is then tilted, and mercury poured into its lower part in such a manner that the zinc plate does not touch the mercury. The mercury is then taken up, by means of some clean cotton waste tied to the end of a stick, and rubbed over the wet plate. When the whole of the plate has assumed a bright appearance, it is washed in running water, and set vertically to drain in a pan. This may be done at the end of the day, so that the plate has all night to get rid of its superfluous mercury. In the case of thick plates, and none should be thinner than one eighth of an inch, the process may be repeated with advantage. The mercury remaining in the pan and that drained from the plates may be used for future amalgamations. In very large operations, instead of a pan, a well-made shallow trough of red pine may be employed for amalgamation. Napier, in his "Electro-metallurgy," states that for every effective square foot of zinc 1½ ozs. of mercury are necessary in the first operation, and for the second and all subsequent operations upon the same plate half that weight. We have tried this upon a large scale, and find it to be correct. This form of galvanic battery was invented by William Hyde Wollaston, doctor of medicine, in the year 1815.* In its original shape each surface of the zinc plate was opposed to two copper plates, thus making the whole surface of the zinc electrically effective. Although it has since been improved, and the use of amalgamation † has been generally adopted, it still goes by the name of Wollaston's battery.

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* See Specification of Patent, No. 1183, filed by Claude Joseph Edme Junot, and dated December 28, 1852.

† See Specification of Patent, No. 1183, filed by Claude Joseph Edme Junot, and dated December 28, 1852.

‡ See Specification of Patent, No. 1183, filed by Claude Joseph Edme Junot, and dated December 28, 1852.

§ See Proceedings of the Royal Society, vol. xii. p. 438—William Crookes.

Platinized-silver Zinc Battery.—In this arrangement it is sought to provide for the free evolution of the hydrogen gas given off at the negative plate during the action of Wollaston's and other like batteries, and to keep the negative plate clean and uniform by coating a plate of silver with platinum. Virtually, therefore, this battery is not a silver-zinc, but a platinum-zinc combination. The platinum is deposited upon a plate of thin silver foil as a black powder, strongly adherent, and forming a surface composed of a great number of fine points. To a top frame, and on each side of it, vertically, an amalgamated zinc plate is clamped, by the same screw that serves to attach the conducting wire to the plate. The silver plate is mounted in a vertical frame (as in the frame of a picture) attached to the top frame and between the zinc plates. In large batteries the frame may be made in half, vertically, so that the silver plate can be laid between and the two halves fixed together by means of wooden pegs or tree-nails. Mahogany is a suitable wood to make the frames of, as it will stand the acid if the wooden pieces be baked and then well payed over with a solution of shellac in pyroxylic spirit prior to being made up into frames. The only practical method of preparing the silver plate is to put the cleansed and roughened plate into a vessel containing a solution of chloride of platinum. In this liquid a porous cell containing an amalgamated zinc plate is placed. The liquid in the porous cell is weak sulphuric acid—1 part by measure of acid to 20 parts of water. The same acid mixture, containing per fluid oz. a few drops of neutral chloride of platinum, is the outer liquid. On connecting the zinc plate to the silver by a conducting wire, an electric current is generated, and passes from the zinc to the silver, depositing the platinum upon the silver in the state of a fine black powder. This method of generating an electric current in the same vessel as that in which the deposition of metal occurs is called the "single cell process." It has been alluded to in the description of the second solution for depositing copper. The silver plate thus prepared should not be touched by the hand. It may be again platinized when requisite. In this battery, the exciting solution best adapted for electro-metallurgical purposes is the same as that employed in Wollaston's battery. It should be used with the same restrictions as to saturation as those attended to in working Wollaston's battery. A good method of using the platinized-silver zinc battery, when it is to be kept long in action, consists in having the vessel in which the plates are placed more than double the height of the plates. In this case, during the action of the battery, the heavy sulphate of zinc descends to the bottom of cell as fast as it is produced, and an equal volume of unused acid solution rises. The battery being fixed on a shelf, so as to be perfectly without disturbance, the height of the saturated solution increases until half of the vessel is occupied therewith. This may be ascertained by means of a glass bulb of suitable specific gravity, which will rise with the strong solution, and will always remain at its surface. When the vessel is half full of the saturated solution, the saturated portion may be drawn off by means of a syphon, placing the short leg near the bottom of the vessel. The vessel may then be filled up with new acid, and worked again until half the liquid is saturated, and so on continuously. The platinized-silver zinc battery was invented in the year 1840, ‡ by Alfred Smee, surgeon to the Bank of England, and it is known by his name.

Iron-zinc Battery.—The presence of free hydrogen on the negative plate of a battery cell causes a rapid diminution of the original electric current. This effect is due to an opposed electro-motive force. In other words, when bubbles of hydrogen gas remain persistently in contact with the negative plate, instead of rising to the surface as they do in Smee's battery, or instead of being absorbed in the liquid, as they are in some batteries, as will be seen further on, such as Daniell's or Grove's, this condition produces, or tends to produce, a current in the galvanic cell in the opposite direction to the main current. That such a current exists may be shown by taking a copper-zinc cell with two copper negative plates separated from each other, and passing the current from one of the copper plates in combination with the zinc plate through the coil of a galvanometer, an instrument to measure the strength of the current, which will subsequently be described; if after this battery current has circulated in the galvanometer some short time, the galvanometer be disengaged from the battery, and its terminals connected with the two copper plates only, the plate which has been in use will act as a zinc plate to the new one brought into work, and the direction and strength of this reflex current will be marked by the galvanometer. As, in the usual galvanic arrangements with one fluid only, neither a highly oxygenated liquid can be used, nor a liquid with any metal in solution that will absorb the hydrogen as fast as it would otherwise be formed, it is exceedingly difficult to construct a cell with one fluid only that will not become subject to the action of this reflex current. The action of the reflex current is called polarization.

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* See Philosophical Transactions, 1815, p. 363.

† Invented by Kemp (liquid amalgam) in 1828, and Sturgeon (rolled zinc plates amalgamated) in 1830. See Sturgeon's Annals of Electricity, Magnetism, and Chemistry, vol. i. p. 81; also Sturgeon's Lectures on Galvanism, p. 135.

‡ See *Philosophical Magazine* for April, 1840.

About the year 1830 WILLIAM STURGEON,* late lecturer on science at the Royal Victoria Gallery of Practical Science at Manchester, invented a single-fluid battery with cast-iron and amalgamated zinc, excited by weak sulphuric acid. This battery is found to be very constant, and its hydrogen is freely given off, even when the battery is out of action, for the iron is dissolved by the acid; but this constant charging of the acid solution with sulphate of iron, together with the continual diminution of the iron, has prevented it from being used extensively. WALENN states that, having experienced the benefits of STURGEON'S battery, he sought to remedy these defects, and to effect other improvements, which he believes he has succeeded in doing.† The follow-ing arrangement is the one which, after some experience on a large scale, he has found to work well. The plates are mounted as in WOLLASTON'S battery, in a top frame, the amalgamated zinc plate being between two cast-iron plates; the solution used is a half-saturated solution of protosulphate of iron, with a slight addition of sulphuric acid. The cast-iron plates should be of metal that contains a considerable amount of carbon, and is what the workmen call "keshy." This metal runs very freely, and thin plates of it (say one-eighth of an inch in thickness) are easily cast. Prior to use in the battery, the plates may be left twenty-four hours in weak sulphuric acid, to take off the skin and to establish the kind of surface upon them that gives the best result; this surface should not afterwards be interfered with. The zinc plates are not amalgamated in the ordinary way, but are coated with lead as well as with mercury. The best way to accomplish the coating is to dissolve bichloride of mercury in weak hydrochloric acid, and to add thereto a solution of acetate of lead, about equal weights of the salts being used; the zinc plates, already cleansed, are dipped into this compound solution, and they receive a coating of mercury and of lead at the same time. The mercury should be in excess of the lead. A battery thus constructed is remarkably constant, and does not decline in power from the effects of polarization. If an ordinary amalgamated zinc plate be substituted for that described above, it will be found, on galvanometric measurement, that the electro-motive force of the latter arrangement is exactly half that given by the cell with the leaded plate. During action, iron is electro-deposited upon the negative plate; when the battery is inactive, solution of the iron slowly goes on. A good method of using this battery on a large scale is to place the iron and zinc plates in grooves in a wooden trough, and to run off the liquid into another spare trough when it is not wanted. This galvanic arrangement will bear further investigation.

Single-cell Apparatus.—This is a galvanic cell and depositing apparatus in one. The article to be coated constitutes the negative plate of the battery, and the coating solution forms at the same time a second solution in the galvanic circuit, a porous partition being between the solution that excites the zinc plate and that which aids the electric current, and at the same time deposits metal. For electrotypy this apparatus has especial advantages; the arrangement used is an outer cell containing a solution of sulphate of copper‡ and an inner cell, or several inner cells, containing weak sulphuric acid or a half-saturated solution of sulphate of zinc. The zinc plate is amalgamated, and is connected by a single conductor to the object to be electro-coated. The single-cell apparatus is noticed in this place as a source of electric power; it forms a connecting link between single-fluid galvanic arrangements and double-fluid batteries.

Copper-zinc Double-fluid Battery.—The most general form of this apparatus is a porous cell containing dilute sulphuric acid placed in an outer vessel containing an acid solution of sulphate of copper. An amalgamated zinc rod forms the positive element in the porous cell, and a hollow cylinder of copper forms the negative element in the outer vessel. In this battery, as well as in the single-cell apparatus for the electrotype, a perforated shelf, near the top of the outer vessel, and inclosing the top of the porous cell as by a ring, serves to supply crystals of sulphate of copper to the solution, in the place where they are most likely to equalize the density of the solution, namely, at the top thereof. The electrolysis of the sulphate of zinc solution causes the acid of the sulphate to attack the zinc plate, the base (zinc) at the porous cell finds another proportion of acid to unite with, this being supplied from the sulphate of copper, and the copper is continually reduced upon the negative plate in the metallic form during the action of the battery; thus a constantly renewed and perfectly clean surface is provided for the conduction of the current, and no polarization can take place, for no hydrogen or other substance foreign to the negative plate is produced there. The chief reason why this battery has full description here is, that the principles of its action most tersely illustrate the laws of electro-deposition and of electrolysis, for it is a depositing cell as well as a galvanic battery. It is the most constant of all galvanic combinations at present known. The copper-zinc double-fluid battery was invented by Professor DANIELL§ of King's

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* See Sturgeon's Lectures on Galvanism, pp. 135–37.

† See Report of the Meeting of the British Association at Birmingham in 1849; Transactions of the Sections, p. 45.

‡ See the head, Solutions for Electro-depositing Metals—COPPER.

§ See Philosophical Transactions, 1836.

College, London, in 1836, and it is universally known by the name of DANIELL'S battery.

Platinum-zinc Double-fluid Battery.—A porous vessel containing a sheet of platinum immersed in strong nitric acid is placed in an outer vessel containing an amalgamated zinc plate, together with weak sulphuric acid. The nitric acid yields up some of its oxygen to the hydrogen that would otherwise be evolved, and forms water; thus all tendency to polarization is avoided, and the platinum plate being indestructible in nitric acid, constantly keeps clean. This battery is the most powerful arrangem nt known; unfortunately the decomposition of the nitric acid in the presence of air yields peroxide of nitrogen, a red gas of very poisonous qualities. This galvanic battery is known as GROVE'S battery; it was invented in the year 1839 by Professor GROVE, now Sir WILLIAM ROBERT GROVE, Justice of the Court of Common Pleas.

Carbon-zinc Double-fluid Battery.—This combination is a modification of GROVE'S, in which a rod of carbon is substituted for the platinum. A solution that is sometimes used with this battery is made by mixing together equal measures of sulphuric and nitric acids. This battery is sometimes employed to electro-deposit copper and brass upon iron. This arrangement is by M. BONIJOL; it is a modification of Professor BUNSEN'S plan, in which the carbon is a hollow cylinder outside the porous vessel. Professor BUNSEN published this invention in 1842.

Galvanic batteries have been treated of at some length, because of their intimate connection with the subject of electro-metallurgy. Not only is the single-cell apparatus a particular case of a DANIELL'S battery, but, in series, any battery cell that is more charged with zinc than others may become a depositing cell. The amount of zinc consumed in each cell of a battery in a given time is a direct measure of the work done in the electro-depositing trough in the same time. The history of the subject is, moreover, intimately bound up with that of the galvanic battery (in preference to any other generator of electric force), for the penny piece that SPENCER substituted for the negative plate of a DANIELL'S battery, in 1837, was the forerunner of all electro-metallurgical discovery.

The chief characteristic of the galvanic battery, the old and tried but somewhat expensive and rather troublesome friend of the electro-depositor, is its continuity and constancy. For experimental and laboratory operations, perhaps, it will never be entirely discarded, for it can be adjusted with readiness and ease to the kind of work to be done.

Magneto-electric Machines.—The excitation of electric power by means of mechanical labour, combined with magnetic force, is a result of the discovery by FARADAY, in 1831, that when a steel permanent magnet is introduced into a hollow cylindrical coil of insulated wire, a current of electricity is induced in the wire of the coil, and during the withdrawal of the magnet from the coil a current in the opposite direction is induced. This property may be stated in a more practical form, namely, that if a soft iron bar (or core) surrounded by a coil, be approached to one of the poles of a permanent magnet, an electric current will traverse the coil, and if it be withdrawn from the same pole the current will be in the reverse direction through the coil. Then, if these reverse and alternate currents pass through a suitably arranged set of springs and contact pieces, they may both be made to issue from fixed binding screws in the same direction. Upon this principle, an apparatus may be constructed to give out a constant stream of electricity, provided that by appropriate motive power, and by means of governing apparatus, a constant and uniform movement of the coils before the magnetic poles is maintained; the only limit to the number of magnets and of coils in a given machine is the space occupied by them, and the power required to drive them. The power required to drive these machines is much more than would be supposed upon a cursory view of the subject; the weight of the masses of copper wire and soft iron cores that form the coils is considerable, but besides the friction due to the motion of these heavy parts, the magnetism of the magnets tends to make each coil (as it passes), stop opposite to a magnetic pole. It must also be borne in mind that there is a limit to the electro-motive force which these machines can produce, this limit being independent of the perfection of insulation and of mechanical resistance; there is a sensible time occupied in changing the magnetic polarity of the soft iron cores, and in reversing the direction of the electric current through the coils. If the speed be increased beyond that at which the greatest change of magnetisation occurs, the electro-motive force will fall off instead of increasing. In spite of these drawbacks, of the original cost of the machines, and of other peculiarities which attend the use of a complicated mechanical apparatus, the introduction of this source of electric power into electro-metallurgical work has increased the productive powers of the art, and tends to cheapen the process, especially on a large scale. The power is comparatively inexpensive, for it is derived from the combustion of coal; it is more in conformity with the mechanical genius of the engineer than is the chemistry and constant manipulation of the galvanic battery, and it is able to be used at any time by the application of adequate motive power.

Many plans have been devised to provide for the necessary alteration of magnetic induction, or for the change of polarity in the cores of the coils of magneto-electric machines. The following may be noted:—WHEATSTONE* mounts pairs of coils on the same axis longitudinally, and rotates them between the poles of fixed permanent magnets. HATCHER† breaks contact between the core and the permanent magnet. DUJARDIN‡ breaks contact between the fixed permanent magnet and its armature, the ends or poles of the magnet being enveloped by the coils. Nollet[*] mounts his cores in the rim of a wheel, and rotates them in front of similarly placed fixed permanent magnets. Bain[†] revolves the permanent magnets. Allan[‡] has radial coiled cores revolving between permanent magnets placed in the circumference of a circle. Henley[§] short-circuits every alternate current. Hjorth[‖] employs coiled cores amongst the fixed permanent magnets, and excites their magnetism by a portion of the current from the moving coils. Holmes[¶] has a symmetrical arrangement of coils and magnets, the coils being in a ring between rings of fixed permanent magnets. Henley,[**] in a further invention, uses armatures (not coiled), revolving in front of the coiled cores and permanent magnets. Since these inventions, other principles have been successfully brought to bear, so as to assist in perfecting the magneto-electric machine. The chief improvements that have taken place are based upon:—1st. The principle of accumulation. 2nd. Continuous magnetization.

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* See Specification of Patent, No. 9022 (old law), filed by Charles Wheatstone, and dated July 7, 1841.

† See Specification of Patent, No. 11,634 (old law), filed by William Henry Hatcher, and dated March 23, 1847.

‡ See Specification of Patent, No. 11,894 (old law), filed by Pierre Antoine Joseph Dujardin, and dated October 7, 1847.

Fig. 4.

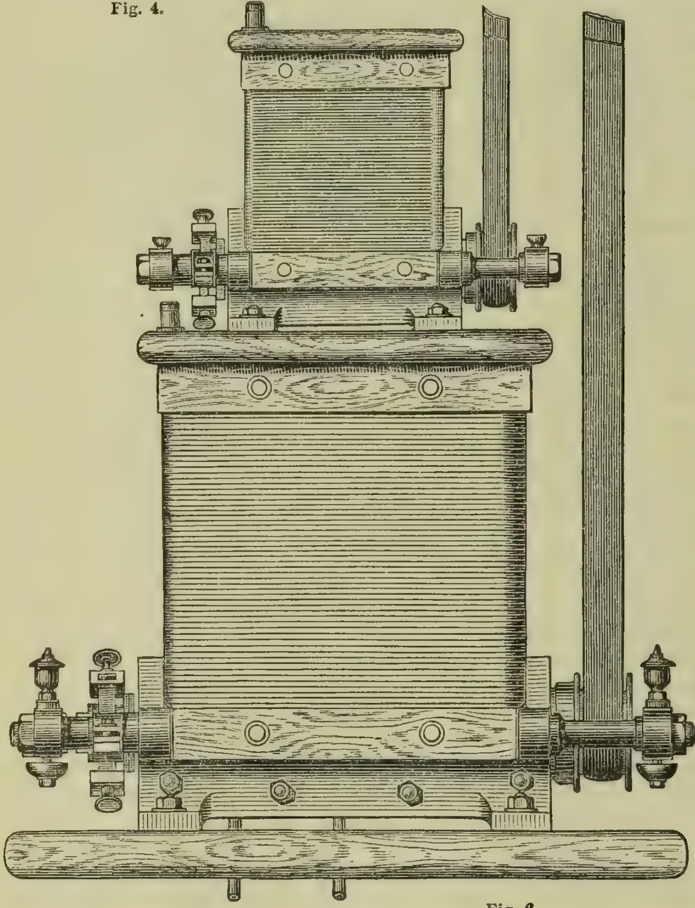


Fig. 5.

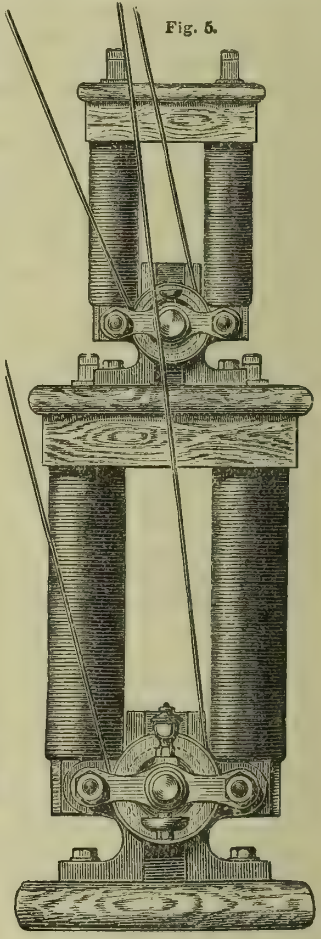


Fig. 7.

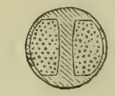
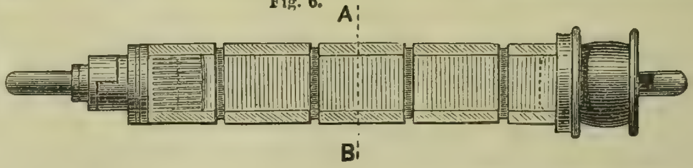


Fig. 6.



Wilde's Machine.[††]—The principle of accumulation is employed in this powerful apparatus. According to this principle, the electric current from a small

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[*] See Specification of Patent, No. 13,302 (old law), filed by Edward Clarence Shepard (a communication from Floris Nollet), and dated October 24, 1850.

[†] See Specification of Patent, No. 14,146 (old law), filed by Alexander Bain, and dated May 29, 1852.

[‡] See Specification of Patent, No. 14,190 (old law), filed by Thomas Allan, and dated June 24, 1852.

[§] See Specification of Patent, No. 2846, filed by William Thomas Henley, and dated December 8, 1853.

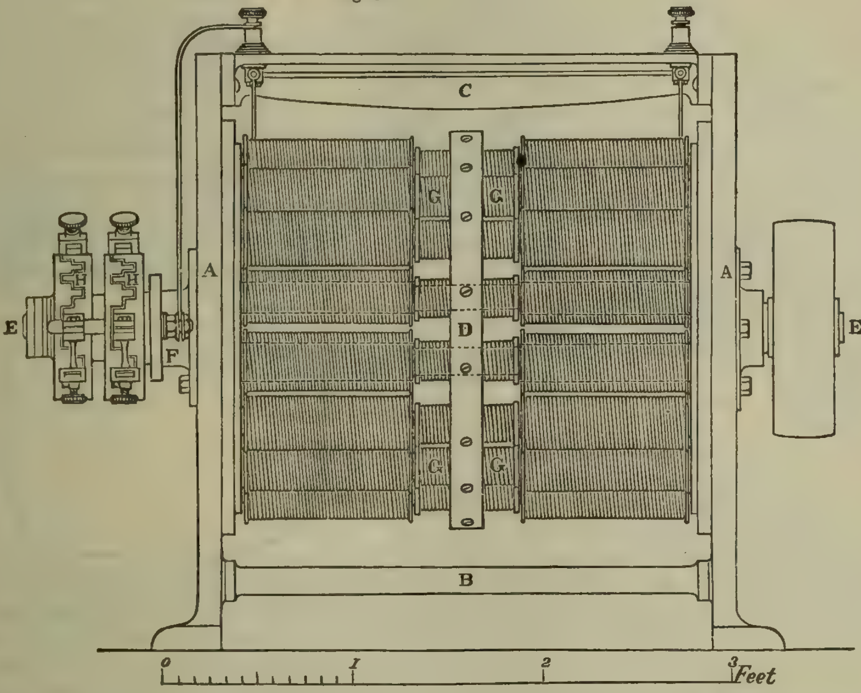
[‖] See Provisional Specification, No. 2198, filed by Soren Hjorth, and dated October 14, 1854.

[¶] See Specification of Patent, No. 573, filed by Frederick Hale Holmes, and dated March 7, 1856.

[**] See Specification of Patent, No. 2769, filed by William Thomas Henley, and dated November 22, 1856.

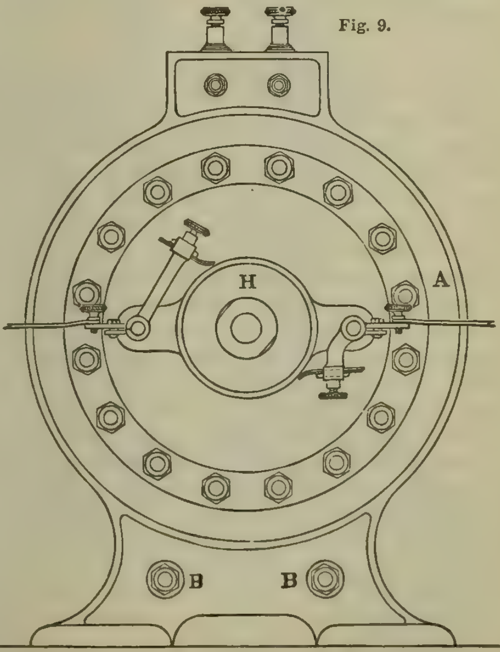
[††] See Philosophical Transactions, 1867, vol. 157, p. 89.

Fig. 8.



magneto-electric machine (which may be called No. 1), is made to excite the electro-magnet of a large machine (No. 2); the current from No. 2 may excite the magnet of a larger machine (No. 3); that from No. 3 may excite the magnet of a still larger machine (No. 4), and so on until the required power is obtained; the electric current for depositing metals or for other use is taken from the moving coil or coils of the last machine. The advantage gained by this arrangement is very considerable, owing to the remarkable fact that a much greater amount of magnetism is developed in the electro-magnet than that which exists in the permanent magnet of the magneto-electric machine employed to excite it. Practically, only two machines are required, and a portion of the current from the small machine is used to increase the magnetism of its permanent magnet, by converting it into an electro-magnet. The small machine is generally mounted on the top of the large machine, as shown in Figs. 4 and 5. The armature is a Siemens' armature,* that is to say, the coil is wound on a bar in the direction of its axis (*i.e.*, longitudinally), instead of round its axis. This is shown in the longitudinal elevation of the armature, Fig. 6; the outer casing is partly removed to show the coil. Fig. 7 is a transverse section through A B, in Fig. 6. A machine of this description,† with an armature 3½ inches in diameter and 18 inches effective length, will deposit 28 ozs. of silver per hour, when it is driven at a speed of about 2000 revolutions per minute by means of a two horse power steam-engine.

Fig. 9.



The principle of accumulation may be adopted in the same machine, instead of using more than one machine for the purpose. Even if the permanent magnetism in the inducing magnet be very weak in the first instance, if a part of the current generated in the moving coil or coils be passed through a coil that encompasses the inducing magnet, the motion of the machine produces a current which reacts upon the magnetism of the inducing magnet, and, under favourable circumstances, may be made to increase until the resistance of the coils, as they pass the poles, balances the driving power. The most practical form of this machine is one in which there are many coiled armatures, for by this arrangement the heat manifested in the coils is disseminated and dispersed, and some of the coils may be especially devoted to generating the current that increases the power of the fixed magnets; this current is called the minor current, the current useful for external work being the major current. A machine with multiple coiled armatures is shown in Figs. 8 and 9;[*] Fig. 8 is a front elevation, and Fig. 9 an end elevation. This machine consists of a vertical cast-iron disc, mounted on a horizontal driving shaft, and carrying sixteen coils, which project on both sides of the disc, so as to form thirty-two armatures. The disc is placed between two circles of fixed magnets, each circle consisting of sixteen magnets projecting inwards from the framing. The two circles of magnets have their poles opposite to each other, and in one position the coils are between opposite poles of the magnets. The ends of the cores are terminated with iron plates of a circular form, which answer the double purpose of retaining the helices surrounding the cores in their places, and overlapping, for a short distance, the spaces between the poles of the adjacent magnets. The fixed magnets are coiled with wire, through which a portion of the current is made to circulate, and their initial magnetism is imparted to them, in the first instance, by another magneto-electric machine. They retain sufficient permanent magnetism to enable it to be exalted to the required degree by the working of the machine, and the major current may be used for electro-metallurgical or other purposes. The minor current is furnished by four of the armature coils. The major current is kept separate from the minor current, and has a separate arrangement of springs and contact pieces to bring the opposite and alternate currents into one current, which is practically continuous. The speed of the central shaft may be from 300 to 1000 revolutions per minute. A is the vertical circular framing of the machine; B B, stay rods; C, bridge; D, heavy disc; E, E, driving shaft; F, insulated bearing; G, G, G, G, cores or armatures; H, the springs and contacts, or "commutator" for the minor current; H′, the commutator for the major current. A machine with multiple armatures is now in use by Messrs. Elkington. This powerful apparatus is of the size indicated in the scale to Figs. 8 and 9, and has more than thirty-one times the power (to deposit metals) of the machine shown in Fig. 4; it deposits 4½ cwts. of copper per day of twenty-four hours.

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* See Provisional Specification, No. 2107, filed by Charles William Siemens, and dated September 10, 1856.

† The following Specifications, filed by Henry Wilde, relate to magneto-electric machines of the accumulative kind:—No. 516, 1863; No. 3006, 1863; No. 1412, 1865; No. 2762, 1865; No. 3209, 1866; No. 842, 1867; No. 618, 1873.

Professor Wheatstone, Dr. Werner Siemens, Mr. Ladd, and some others have added their quota of experience and work to perfecting accumulative machines.

Gramme's Machine. — This machine differs from all other magneto-electric machines at present known, inasmuch as it is the only one that gives a continuous current in one direction.[†] The current from this machine depends upon the uninterrupted travelling of the magnetic poles of the core in a circle, that is, upon continuous magnetization. An engraving of two examples of this machine is shown in Plate I., figs. 1 and 2. If, instead of introducing a magnet into a coil, as in Faraday's experiment of 1831, one pole of a magnet be presented to the outside of a coil containing a soft iron core, the magnet being at right angles to the core, as shown in Fig. 10, a uniform electric current will be generated in the coil during the uniform movement of the magnet parallel to the axis of the coil—say from left to right, as indicated by the arrow. This current, however, will cease when the magnet arrives at the extremity of the coil, as shown in dotted lines. To make it continuous, it is necessary to make the core, together with its coil, continuous. This can be done by bending the core and coil into the form of a ring or annulus. This is shown in Fig. 11; and if the mag-

Fig. 10.

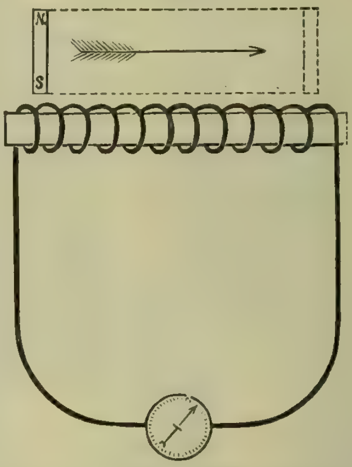
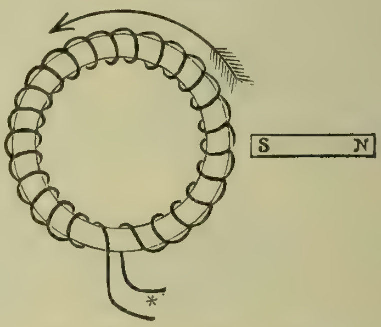


Fig. 11.



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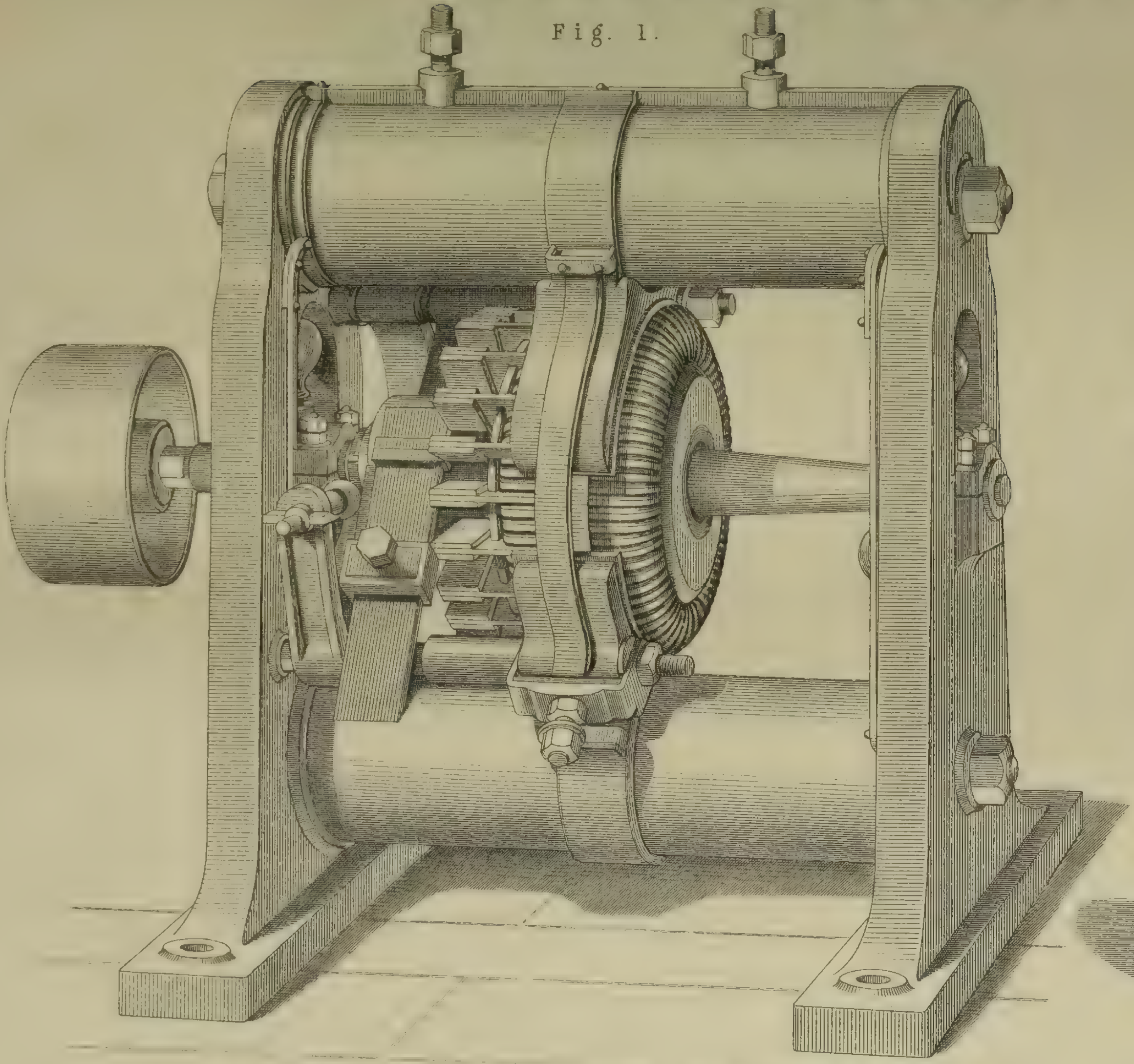
[*] See *Philosophical Magazine*, June, 1873.

[†] See Specifications of the following Patents:—No. 1668, filed by Zenobe Theophile Gramme and Eardley Louis Charles D'Ivernois, and dated June 9, 1870; also No. 1254, filed by John Henry Johnson (a communication from Zenobe Theophile Gramme and Eardley Louis Charles D'Ivernois), and dated April 26, 1872.

ELECTRO METALLURGY.

PLATE I.

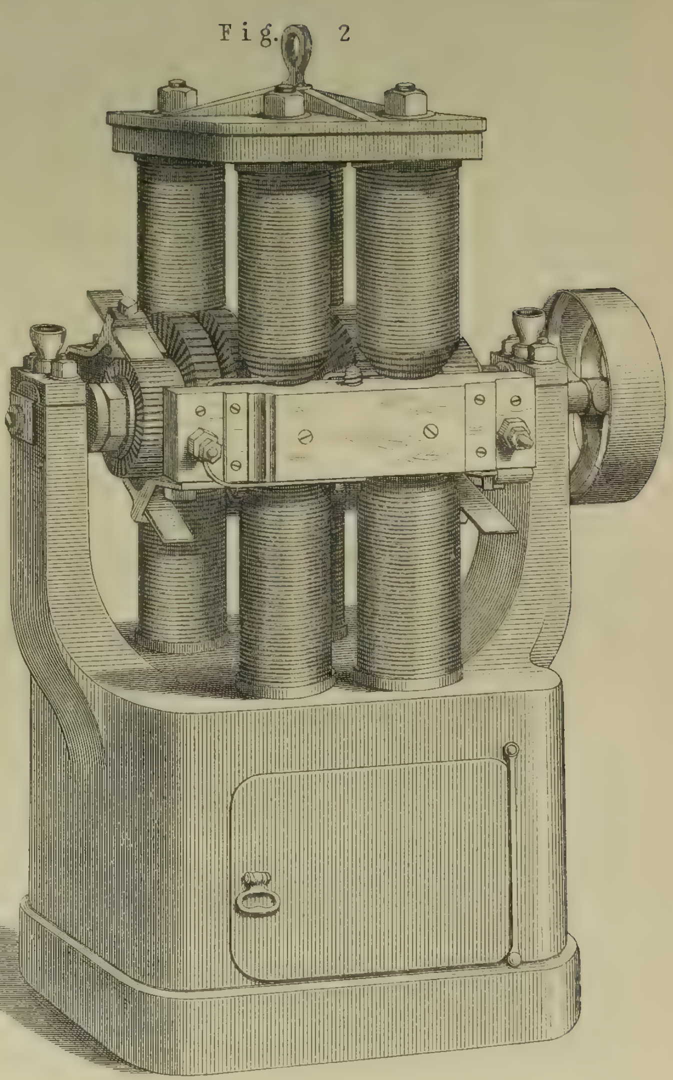
Fig. 1.



GRAMME'S 4 CWT. MACHINE.

Height 2′ 1″. Breadth 2′ 4″. Depth 1′ 10″

Fig. 2



GRAMME'S 12 CWT. MACHINE.

Height 4′ 5″ Breadth 3′ 2″ Depth 2′ 0″

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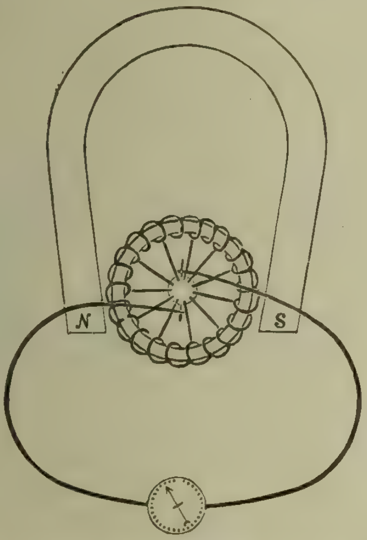
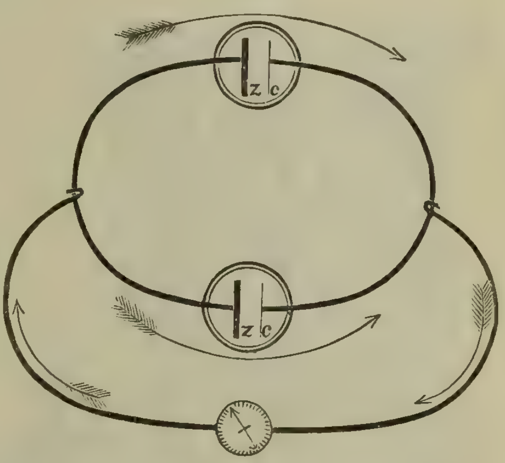
net, S N, were to rotate round the annulus, its path being the circumference of a circle concentric to the annulus, a continuous electric current would circulate in the coil when the extremities of the coil were joined. This, however, would be a very unmechanical method of constructing a machine, and in practice the magnet is fixed and the annular core revolves; moreover, it is best to use both the poles of the magnet, and not merely the south pole, as shown in Figs. 10 and 11. This is the form in which the machines shown in Plate I., figs. 1 and 2, are constructed, and which is represented as a diagram in Fig. 12. In the machines figured in Plate I. a part of the current is used to magnetise the magnet; and the necessity to utilize the north pole as well as the south of the inducing magnet causes two continuous, simultaneous, and opposite currents to be generated in the annular coil, one current being in that part of the coil under the influence of south magnetism, and the reverse current being in the other half of the coil As will be seen presently, by an illustration, this condition obliges the coil to be made round the annulus in a perfectly continuous manner, and the current for useful purposes is taken from fixed points that lie in the line at right angles to the line joining the magnetic poles. Practically this is done by taking from the coil equidistant radii, and connecting them to separate longitudinal metallic strips on the surface of a non-conducting drum. Springs at the fixed points press against these revolving strips, and binding screws upon the springs enable conductors to proceed conveniently from the machine to the work to be done. If it be asked, How is it that in a continuous metallic circuit two electric currents in opposite directions can exist at the same time, so as to be available for use outside the closed circuit, a reference to the diagram, Fig. 13, will answer the question. The constant and local excitation of the upper magnetic pole upon its half of the annulus may be compared to the upper galvanic pair in the figure, and the state of the lower half of the annulus may be compared to the lower galvanic pair, the arrows indicating the direction of the current in each half circle. It is easily seen that this arrangement is only that which is common in galvanic batteries, and known (in old language) as quantity connection and (in recent nomenclature) as connection in multiple arc, and is the same as if in two galvanic batteries both zincs were connected to form a double zinc, and both coppers were joined to form a double copper. But this is equivalent to a single cell with double the area of plate of each of the cells in question; thence by analogy it will be readily perceived that the powers of each half of the annulus are added together without in the slightest degree interfering with one another, and that, thanks to the fixed points, they furnish a continuous and a double current.

Fig. 12.



The machine, Fig. 1, Plate I., weighs 4 cwts., and at 400 revolutions per minute deposits 1 lb. of silver per hour, when driven by a small fraction of a horse power. That marked Fig. 2 weighs 12 cwts., and deposits 6 lbs. of silver per hour; this machine requires two horse power, and is driven at a speed of 300 revolutions per minute.

Fig. 13.

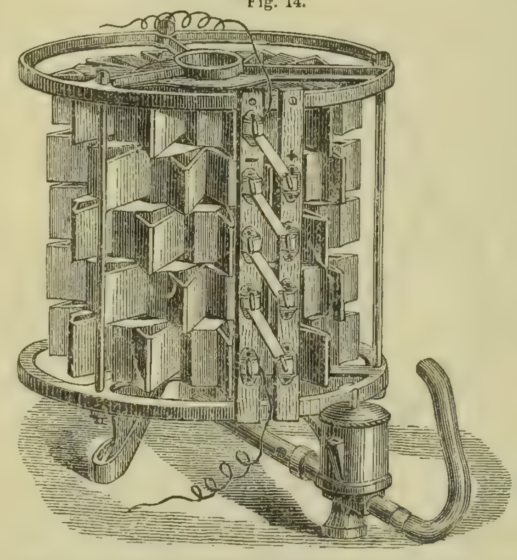


The peculiarities of magneto-electric machines are their great power, economy, and readiness of action.

Thermo-electric Batteries. — If bars of dissimilar metals be joined at their extremities, and made a part of a closed, insulated, metallic circuit, which may be an electric circuit, the heating of the place of junction of the metals generates a current of electricity in the circuit; and as the current is due to heat, the electricity furnished thereby is called thermo-electricity. This fact was discovered in 1823 by SEEBECK in relation to bismuth and copper; he found that the current went from the bismuth to the copper across the heated junction. Since then bismuth and antimony have been used, and a number of other thermo-electric pairs have been tried. All, more or less, are subject to certain drawbacks. If the alternate junctions be cooled, say by means of ice, the power of the current is increased, for in general it bears a direct ratio to the difference of temperature between neighbouring junctions; therefore, unless specific arrangements are made to supply at the proper place definite amounts of heat and cold, the strength of the current varies. The whole circuit being metallic, and therefore a good conductor of heat, the general tendency of the arrangement, if kept for some time in action, is to the equalization of the heat, and therefore the declension of the electric power. The contacts of the metals, under the influence of heat, are liable to become in time more and more imperfect. These circumstances, combined with the fact that nearly all metals are altered in physical constitution under the influence of heat or cold, have made the construction of thermo-electric arrangements for practical purposes a very difficult matter.

The electro-motive force of thermo-electric batteries, or "thermo-piles," is small in comparison with that of voltaic arrangements. Although in other respects very efficient, a thermo-pile of iron and German silver must have 700 elements to render it of the same power as a single DANIELL'S cell. By using carefully constructed heating and cooling arrangements, an antimony-bismuth pile may be constructed so that only ten alternations are required to produce the same power, but this instrument is liable to get out of order. M. CLAMOND began to publish his experiments in 1873,* and in 1874† the Thermo-Electric Generator Company was formed to work his patents. One form of CLAMOND'S thermo-pile is shown in Fig. 14. In a paper read before the Society of Telegraph Engineers,‡ Mr. LATIMER CLARK describes the latest form of this apparatus. The negative metal (corresponding to the copper in SEEBECK'S arrangement, and to the copper plate in a WOLLASTON'S battery) is composed of an alloy of 2 parts of antimony and 1 of zinc, and the positive element is a piece of ordinary tinned sheet iron. In this plan any splitting of the metals or of the contacts is prevented by casting the bars of negative metal in moulds almost at the temperature of the molten alloy, and cooling them very slowly. The sheet iron, after being stamped out, is fixed into the mould into which the melted alloy is poured. The bars are arranged in a radial manner round a central heat passage, the insulations being accomplished by means of mica and a cement containing powdered asbestos and silicate of potash. Each circle of bars is insulated from the one above it by a ring of dry asbestos, and the entire structure is consolidated by means of cast-iron frames, drawn together by bolts and nuts. In the central heat passage a BUNSEN'S burner (which burns a mixture of gas and air) supplies the heat, which should be about 400° Fahr. at the junctions of the inner bars, and about 200° Fahr. at the outer junctions. According to the latest improvement, a closely fitting movable cover is placed at the top of the pile; the heated gases pass to the top of the heat passage, then descend outside the passage, between it and the elements, to the chimney, by which they have exit into the open air. In piles with small elements the consumption of gas is about 1 cubic foot per hour for each DANIELL'S cell in electro-motive force; that is, for each twenty elements of the pile.

Fig. 14.



A machine of 100 bars, with a consumption of 5 cubic feet of gas, deposits about 1 oz. of silver per hour. The same apparatus, arranged in multiple arc, will deposit about 1 oz. of copper in the same time. 400 large bars, consuming 2 lbs. of coke per hour, will deposit about four times the above quantities in the same period of time.

In some respects it would seem that the electricity of the future, for electro-metallurgical purposes, would be derived from thermo-electric arrangements in preference to all others; for though the thermo-electric apparatus of M. CLAMOND is still susceptible of improvement, it is able to supply electricity in great quantity, and of sufficient electro-motive force to overcome electro-chemical resistances; this machine gives a very constant current, is easily put into and out of action, and is apparently indestructible.

To compare the means of generating the electric current from each source, and the expense of producing electricity that will do a given amount of work in each case: the galvanic battery is continually wasting in itself, the waste being the consumption of metallic and liquid portions thereof, which have to be replaced from time to time; the magneto-electric machine consumes motive power instead of chemical force, and is dependent upon the consumption of coal in a furnace, the supply of water to a boiler, and the wear and tear of complicated parts, some of which are at rest and subject to deterioration from heat, and some in motion, therefore subject to be worn away by friction; the thermo-electric apparatus feeds on heat alone, either of gas or coal, and

* See L'Abbé Moigno's *Les Mondes*, October 9, 1873.

† See Specification of Patent, No. 1199, filed by Charles Clamond, and dated April 6, 1874.

‡ See *Telegraphic Journal* of June 1, 1876, p. 154.

is the single remarkable example of the direct transformation of the energy of heat into electric force, apparently without any other waste than that resulting from the supply of the heat itself, all its parts being rigid and fixed.

Management of Electric Power.—The method of putting into action a galvanic cell has been already explained under the head of Electric Power suitable for Depositing Metals. In order to apply this power, it is necessary in the first place to proportion the size of the cell to the size of the surface to be coated, and the number of cells arranged *in series* to the resistance to be overcome in the solution to be employed, together with the resistance of the wire circuit through which the current passes.

Direction of the Galvanic Current.—In the General View of the Method of Working, it is shown that the direction of the current from a galvanic battery is always from the zinc or positive plate to the copper or other negative plate within the battery, and in the metallic circuit, or other circuit outside the battery, it is from the negative plate to the positive.

In works on the subject this law is sometimes indicated, as in Fig. 15, by + and — marks, + standing for the positive or giving out point or surface, and — representing the negative or receiving point or surface. The free extremity of the wire from the negative plate, C, is called the positive pole, and the free extremity of the wire from the zinc plate, Z, is called the negative pole. This method of describing the direction of the electric current from a galvanic cell also holds good for any number of cells arranged in series; this is shown in Fig. 16, which represents four cells arranged in series. It is essential to note this, for if, as in Cruickshanks' arrangement in series (Fig. 17), the conducting wires between each cell be dispensed with by making each plate double (every zinc plate being soldered to a copper plate), and thus making the plates serve as divisions between one cell and the next, at the beginning and end of the series two plates will serve the purpose of one; and although the zinc plate is the last in the series at one end, and the copper plate the last in the series at the other end, this particular zinc plate might have been left out, and the particular copper plate might have been dispensed with without in the slightest degree altering the electrical effect of the arrangement; for they are simply conductors from the plates in contact with the exciting solution, and the direction of the current is as shown in Fig. 16, that is to say, from the zinc to the copper in the battery, and from the effective copper plate to the effective zinc plate in the external electric circuit.

Fig. 15.

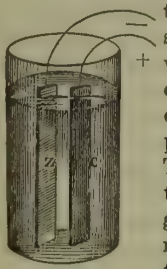
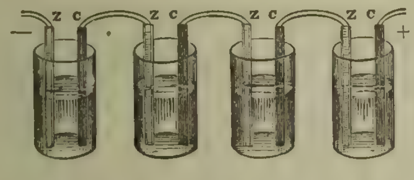


Fig. 16.



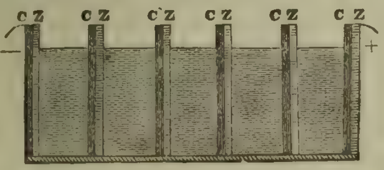


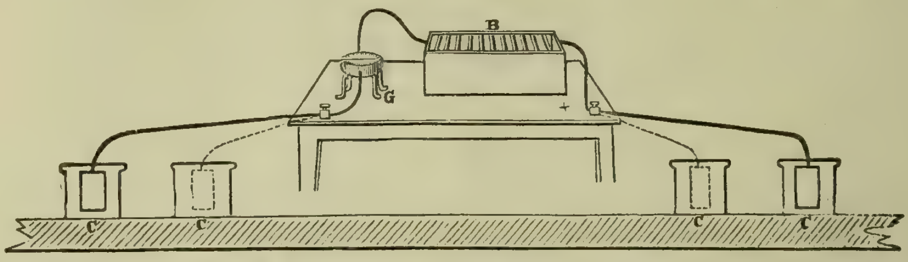
Fig. 17.

Connection of the Battery with the Depositing Trough.—In the depositing cell, in all cases, the positive pole is to be connected to the anode or dissolving plate, and the negative pole to the cathode or article to be coated. In the General View of the Method of Working this point has been put forward in other terms.

Insulation of Batteries.—In arranging batteries for work it is highly necessary to bear in mind that they should be insulated, that is, placed in such a position, and so surrounded with non-conductors of electricity, that no chance may exist of the current, or even a portion of it, returning to the battery without having done its full amount of work in the depositing cell. In small arrangements this point does not require much attention, for the cells are generally formed of earthenware or other non-conducting material; but even in this case it is as well to ascertain that the liquids are not spilt about or over the cells, that the table or shelf is quite dry, and that the wires do not touch or cross each other. The larger arrangements, especially when wooden troughs are used, should be well examined in this respect, for they are generally placed on the floor, or even on the bare ground. The best way of mounting the troughs is upon a horizontal open framework of dry baulks of timber with gutta percha in sheet, or vulcanized india-rubber in sheet, for the troughs to rest upon. If the wood be dry, and in a dry place, that will often be sufficient for practical purposes; but the insulation between each cell, and between the battery and the earth, should be verified by means of a galvanometer, the needle giving no deflection when the insulation is good. If conducting plates be placed in turn in cells of a series (so as not to touch the battery plates), and a conducting wire be taken from each plate to one terminal of a testing apparatus, there should be no deflection of the galvanometer needle. The testing apparatus consists of a galvanometer and twelve-cell battery, which may be of Smee's construction, and half-pint cells. Fig. 18 represents this arrangement, G being the galvanometer, B the testing battery, and *c*, *c*, *c*, *c* the cells whose insulation is to be verified; the dotted lines show the shifting of conducting plates to test the cells in turn. In testing for the insulation of the battery from the earth, one of the conducting plates should in turn be placed in each cell, and the other conducting plate in the ground, moist earth being round it, and the galvanometer and testing battery being in the circuit.

We lay great stress upon testing the insulation of the cells in operations on a large scale, for want of insulation has in such a case given us much trouble, and caused considerable waste of electric power.

Fig. 18.



Size of Battery Plates.—The size of battery to do a given quantity of work is estimated by the effective area of zinc surface in each cell, the *effective* surface being that portion of the zinc plate which is immersed in the exciting liquid, and which is opposite to a negative battery plate. In the usual arrangement of a WOLLASTON'S battery (one zinc between two coppers), both surfaces of the zinc plate are effective; but in SMEE'S battery (platinized silver between two zincs), only one surface of each zinc plate is effective. The size of the zinc plate depends upon the battery used and the metal to be deposited. For depositing copper from an acid solution, by means of a separate battery (WOLLASTON'S), the area of the cathode in the depositing trough may be twice the area of the zinc plate in the cell, especially if more than one cell in series be used; or it may be half the area of the zinc plate. For a cyanide solution of silver, in depositing from which three cells in series are used, the area of the cathode may be from six to eight times that of the zinc plate in each cell. The relative power of the batteries in common use to deposit metals may be stated approximatively, although much depends upon the metal to be deposited and the solution used. The following proportions are true for a sulphate of copper solution in which the electrodes are double the size of the zinc battery plates:—

Kind of Battery.	In action for one hour.	In action for seven hours.	Inverse proportions.
Grove, ...	5·78	5·16	0·19
Single cell, ...	3·44	3·46	0·29
Daniell, ...	1·83	2·52	0·40
Smee, ...	1·22	1·07	0·94
Wollaston, ...	1·00	1·00	1·00

The inverse proportions represent very nearly the effective area of zinc in each cell, that will do the same amount of work in a given depositing trough.

Quantity of Electricity and Electro-motive Force.—The ability of a given quantity of electric force to do a certain amount of work in a given time, to deposit metals, depends upon how much of the force which the battery is capable of generating can pass through the depositing liquid. This varies with the kind of liquid, the heat to which it is subjected, and the distance between the anode and cathode. Acid liquids are more conductive of electricity than alkaline liquids, that is, they oppose less resistance to the passage of a given current. Hot liquids are more easily traversed than cold solutions, and a near approach of anode and cathode favours conduction. For this reason, when one cell in series is sufficient for depositing copper from a solution of the sulphate, it requires three cells to deposit silver from a solution of the cyanide; and six cells is a good power to use with the ordinary alkaline coppering or brassing solutions already described, each cell being coupled with the next in series, as put forward in Fig. 16. Owing to the increase of power from the easier passage of the current due to arrangement of cells in series, a somewhat smaller cell may be used in the case of a number of cells being so coupled up. The coupling up of cells in series, however, has only this collateral relation to the area of the cathode, the direct relation being the effective area of the zinc plate in each cell. For this reason, in the old nomenclature of electro-metallurgy, a galvanic battery coupled up in series is said to be arranged for intensity. The foregoing action of a battery arranged in series is due to the fact that, in such an apparatus, the weight of zinc consumed in a given time in each cell bears an exact ratio to the weight of the metal deposited, and the weight of zinc consumed in a given time in each cell is exactly the same. For instance, for every 65 parts, by weight, of zinc consumed in each cell, there are 63·5 parts of copper deposited upon the cathode, and 216 parts of silver deposited.

When large surfaces are to be coated, the whole of the effective zinc surface cannot be conveniently placed in one cell; an arrangement like that shown in Fig. 19 is therefore employed. In the diagram, Fig. 19, four cells of equal size are shown in plan, arranged so that the same conductor is connected to all the zinc plates, the other conductor being connected to all the copper plates. The effect of this method of coupling up cells is the same as that of a single cell with plates four times the area of each of the cells so coupled up. It used to be called the connection for quantity, now it is called the connection in multiple arc. The practical advantage of such a method is manifest when the cleaning or platinizing of the plates is taken into account; all the cells should be alike and the exciting liquid kept at the same specific gravity in each; it is possible, however, to work with cells of different sizes, provided that the proportion of exciting liquid to area of zinc plate in each cell be kept the same. In this case, if $a_1, a_2, a_3, a_4, \ldots\ldots\ldots a_n$, be respectively the effective areas of the zinc plates in n cells so coupled, the total effective area of the combination will be $c_1 + a_2 + a_3 + a_4 + \ldots\ldots\ldots + a_n$, or the sum of the areas of all the zinc plates employed.

A combination of the arrangement of cells in series and in multiple arc is often used where it is necessary to have a specific electro-motive force to overcome the resistance of the solution, as in silver plating, and where the article or articles to be coated demand a certain effective area of zinc plates to enable the work to be done. This is shown in Fig 20, in which batches of four cells connected in multiple arc are connected in a series of three, making in all twelve cells.

Putting aside for a moment the point of how much metal is deposited by a given galvanic arrangement, and only regarding the substitution of one kind of battery for another, in respect to the number of cells of each kind of battery required to overcome resistance (and therefore arranged in series), if a given resistance can be well overcome, or what is the same thing in electro-metallurgy, if a good quality of metal can be deposited in a fairly short time by a GROVE's cell of a given size, it will require three and three-quarter cells of a WOLLASTON battery of the same size, arranged in series, to do the same quality of work in the same time, or three cells of SMEE's construction. In other words, the intensity, or, more properly speaking, the available electro-motive force of a GROVE's battery is three times that of a SMEE's battery, and three and three-quarter times that of a WOLLASTON's battery.

In arranging galvanic cells in series it is necessary that they should all be exactly alike. This requirement is necessary, otherwise, instead of the work done by the combination bearing a relation to the area of plate in each cell, it will only be proportional to the effective area of the smallest zinc plate. Another reason for the preservation of this similarity is, that if any cell be more charged than the rest with sulphate of zinc in solution, it has a strong tendency to become a depositing cell in the series, and to throw down its zinc on the negative plate, thus lowering the available power of the whole arrangement.

Fig. 19.

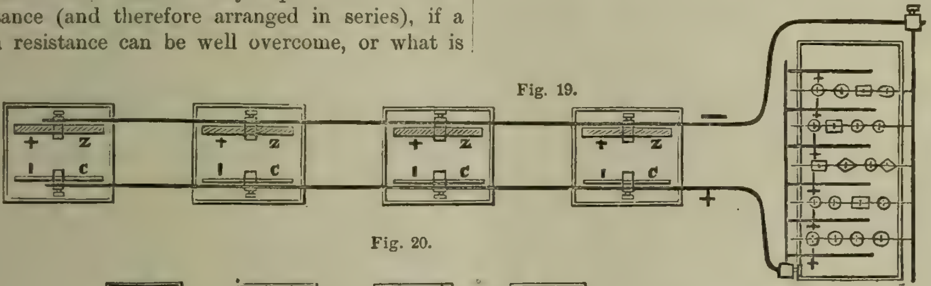
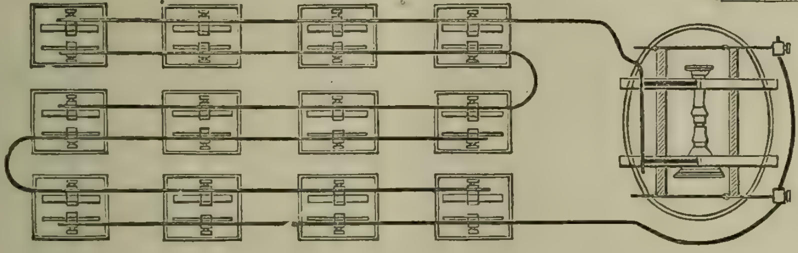


Fig. 20.



Management of Battery Liquids for Continuance.—In the account of SMEE's cell, under the head of Electric Power Suitable for Depositing Metals, an admirable plan is described for managing a battery liquid when the battery is required to be in action for some time. This plan may be used with other battery arrangements. Another plan, which we have used successfully in large operations, is to make the exciting liquid traverse from a large upper tank through the series of cells to a lower tank; from the lower tank the liquid may be pumped up to the upper tank, and the circulation may be thereby continued until the liquid is exhausted. The lower tank should be of sufficient cubical content to contain the whole of the liquid which is in the cells at one time.

Treatment of Battery Plates.—The plates of a battery require attending to from time to time, especially when no provision is made for the circulation of the liquid, or for the removal of the sulphate of zinc in solution from proximity to the negative plates.

In a battery that is in constant work the zinc plates should be taken out every evening, and brushed with a stiff hair brush. If any dark places or spots free from mercury be found, these should be treated with weak sulphuric acid and mercury, so as to render the amalgamation perfect. The plates coated with lead as well as with mercury, as explained under the head of the iron-zinc battery, do not require attention so often. The zinc plates should never touch the negative plates whilst they are wet.

The copper plates of a WOLLASTON's battery should be examined every week. If they appear dark they should be scrubbed with emery cloth till they are quite bright. Especial care should be taken to remove any zinc deposit that may be upon them, and spots of mercury should be removed by heat. It is a good plan to heat them red-hot, and to quench them in "dipping liquid" (a compound of nitric and nitrous acids with sulphuric acid), used by brass finishers.

The platinized silver plates of **SMEE'S** battery may be re-platinized by the battery process with advantage every two or three months of constant working. Any zinc that has been reduced upon them may be removed by immersion in a strong solution of sulphuric acid.

The platinum plates of **GROVE'S** battery may be occasionally cleaned by heating them red-hot.

The iron and carbon plates of batteries seldom require attention. To revive the activity of a carbon plate after re-burning it in a closed crucible, it is very advantageous to electro-deposit upon it platinum in the form of a black powder.

In cells of large dimensions, to avoid taking them to pieces oftener than is necessary, it is advisable to ascertain, by sight and by hearing, whether any hydrogen gas is given off from the zinc plates when the battery is out of action; a zinc plate which gives off hydrogen requires re-amalgamating. Test plates in each cell are very useful. In a **WOLLASTON'S** battery a strip of copper may be suspended near to the copper plate, but not touching it, and electrically connected to it by a conducting wire; the strip should be 1 inch wide and as deep as the negative plate. A similar strip of amalgamated zinc may be similarly connected to the zinc plate. These plates can be taken out and examined from time to time without interfering with the general arrangement, and their condition is a fair indication of the state of the battery plates. If the power of a battery be found to decline prematurely or unexpectedly, each cell should be separately tested with a quantity galvanometer, and the weak cell restored to the power of the rest by removing any cross connections that may have got in the way, or by strengthening the acid, its specific gravity having been previously ascertained by the hydrometer. Possible leakage of solutions, exhaustion of cupric solution in **DANIELL'S** battery, and broken or corroded connections, should be looked for as causing the loss of power.

Connections, Wires, and Binding Screws.—The connections between the cells of a battery, and from the battery to the depositing trough, are of great importance. In our experience, we have seen much inconvenience and loss of power accrue from want of proper attention to this point, and, in general, much greater care is bestowed upon the connection from cell to cell of the battery than upon the rest of the circuit. The analogy between the flow of water through pipes and the flow of electricity through conductors should always be borne in mind. Even in some large electro-plating establishments fine and long conducting wires are sometimes used where thick and short conductors are required, thus only using a part of the total current of the battery.

Although electricity flows fast and copiously through conductors of suitable metal, having sufficient area in cross section, and being well mounted so as to prevent leakage, there is no force which is capable of such instantaneous stoppage.

For electro-depositing it is necessary to provide for the flow of a voltaic current of considerable amount to and from the depositing trough without sensible diminution from the resistance it may encounter in the metallic part of the circuit. Strips of soft malleable copper are far preferable to wires; they are easier placed in the positions required, for a wire must be of some thickness to convey a strong current, and thick wires are not easy to manipulate; the strips also are easier to fix than round wires. In large operations rods may be used that are self-supporting; the same care must be taken to insulate these as to insulate the battery cells and the depositing troughs, for a leakage or cross connection in any part influences the whole circuit. The battery should be as near to the depositing trough as convenient. In circuits which are necessarily long, say several hundred feet, proportionately thick strips will have to be employed. In a **WOLLASTON'S** battery of five cells in series, having an effective area of 144 square feet of zinc surface in each cell, and the circuit to and from the depositing trough being altogether about 200 feet, it is found necessary to use strips one-fourth of an inch thick and 4 inches wide throughout the circuit. Here it may be pointed out that it is not advantageous to have a thick wire at one part of the circuit and a thin wire at another part, except for convenience, and in that case the thin wire of itself must be of sufficient size to carry the whole current. The best method of ascertaining the dimension of the wire practically is by means of a quantity galvanometer; if the wires are of the right dimension the long circuit to and from the depositing trough gives the same deflection (or very nearly so) as the shortest circuit through thick conductors near to the battery. The strips may be fastened by studs to lengths of dried wood fixed in the most available course from the battery to the depositing trough, taking care to make no earth connections, and to keep the return strip away from the forward strip. In cases where the battery has to be a long time in uninterrupted action it is advisable not to use the whole power that the battery can give, but to use, say, three-fourths of it, and to retain the other fourth to make up for weakening of the total power, or for contingencies in depositing; this is accomplished by interposing a thin and long iron strip in a part of the circuit reserved for that purpose, and specially provided with fixtures for altering the strip that is interposed. This method permits of the continuity of the circuit being maintained, even whilst changing the strips, and of plenty of power being in reserve for unforeseen occasions, a rule to be observed in electro-metallurgy as strictly as in mechanics.

In making a connection between the plates of a battery and the conducting wires, respectively, it is necessary to bear in mind that the electric current passes through pure metallic conductors much more easily than it does through rust, oxides, or other compound substances, although they may be in part metallic. The surest way of making electric connection is by soldering, but this is only resorted to when

Fig. 21.

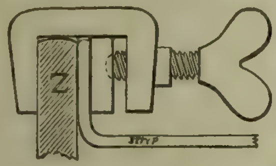
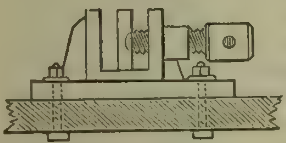


Fig. 22.



the connection is to be permanent. or to be broken at very long intervals. The usual way of making electrical connections in a circuit is to employ clamp screws that are especially suited to the purpose for which they are designed. For small apparatus, a short tube with a screw through the side serves to join one wire with another; for wide strips a ( )-shaped clamp screw, faced on the part of the clamp opposite to the screw, and having a loose plate for the screw to work in, as in Fig. 21, is employed. The figure shows the zinc plate of a battery attached to the conducting wire by this means. In SMEE'S battery it is usual, in small sizes, to clamp and fasten the zinc plates to the top frame by the same screw that is connected to the conductor; this plan should not be employed on a large scale, but zinc plates of more than 4 inches square should be bolted to the top frame independently of the electrical connections. It is often important to have the plates of a battery supported, so that, when all electric connections are removed, they still remain fixed in their places. It may here be mentioned that for ordinary operations one-eighth of an inch is a suitable thickness for zinc plates; for plates 6 feet square three-eighths of an inch is the least thickness that is useful. The copper plates in a WOLLASTON'S battery may be only just thick enough to support themselves in position without bending or buckling. A binding screw, for large works, to fix to a table by bolts, so as to allow of a breakage or adjustment of the electric current at a suitable place, is shown in Fig. 22. It is of great importance to keep the contact surfaces, or bearing plates, of binding screws quite bright and free from even the thinnest film of rust or tarnish, which is done best by scrubbing the face with emery cloth; for this reason binding screws should be kept out of the way of the exciting liquids of the battery, or of the gases given off from the battery. The contact surface of binding screws to carry powerful currents may be one, two, or more square inches, the whole surface being brought into contact by the pressure of the screw. In all cases contact in the circuit should be made with metal against metal.

The Influence of Heat upon Galvanic Batteries.—The influence of heat is to increase the action of a galvanic cell, and to produce a stronger current than the same cell would give at the ordinary temperature. Two causes conduce to this result; in the first place, the application of heat increases the conductivity of the liquid and reduces the internal resistance of the apparatus; it also increases the chemical activity of the battery, causes a greater weight of zinc or other positive element to be dissolved in a given time, and therefore a more powerful action to deposit metals from their solutions. JAMES DICKSON* has made use of these principles to construct a double or triple fluid galvanic battery, in which alkaline sulphides are next to the positive plates, and strong oil of vitriol next to the negative plates; when there is a third, or intervening liquid, it may be dilute sulphuric acid; the whole arrangement is heated by means of steam chambers or otherwise. This principle should be taken into account in selecting a place for a battery; it should not be exposed to great variations of temperature, and should not be at any time lower than 60° Fahr. The position of the battery should be such that dust or metallic particles from a factory do not fall into it; it should be fully protected from the weather, and so placed that pulley blocks, or other mechanical appliances, can be used to raise and lower the plates if they are large.

Galvanometers.—The range of electric power that may be used in depositing from a good solution is generally very great, and the best test of its being able to do the work required of it is by the articles that are coated by it. In coating large objects, however, or when the battery requires to be in action for a long time, it becomes necessary to have from time to time some ready means of ascertaining the power exerted. The ready indication of the quantity of electricity, and of its electro-motive force, is also very convenient when a new battery, or other source of electric power, is being used. Such an instrument exists in the galvanometer, for it shows comparative values by simple inspection. The galvanometer depends upon the principle that, if a wire conducting an electric current be placed in the magnetic meridian, it will cause a magnetic needle freely suspended above it to deflect from the magnetic north and south points; the amount of deflection bears a relation to the quantity or amount of electricity traversing the circuit, and the direction of the deflection depends upon the direction of the electric current.

A galvanometer with a very small needle, and with the conductor separated into two parts, each of which forms a ring or circle, the horizontal axis of which passes through the centre on which the needle is free to vibrate, is called a tangent galvanometer, because the current is proportional to the tangent of the angle of deflection. The best arrangement of the two parts of the conductor, or vertical rings, is when they are in parallel planes separated by a distance equal to one-half their diameter. In the form most available for electro-metallurgy each ring is formed of solid metal, split across at the lower portion, each of the ends thus made being connected to a binding screw. The diameter of the ring may be 18 inches, and the thickness of metal should be such that there is no appreciable resistance to the passage of the electric current. The quantity of metal deposited in a given time by the current measured by this instrument, when it (the galvanometer) is made a part of the circuit, is proportional to the tangent of the angle of deflection of the needle; it may be called a quantity galvanometer. It is important that no other conductors, magnets, or pieces of iron, should be near the instrument, otherwise its indications will be interfered with. If the electric power, whether galvanic, magneto-electric, or thermo-electric, be constant during electro-deposition, the variations of this instrument will indicate changes in the conductibility of the solution.

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* See Specification of Patent, No. 340, filed by James Dickson, and dated February 10, 1862; also, No. 2101, filed by James Dickson, and dated July 24, 1862.

By using a considerable number of cells in series, the character of the metal deposited is altered. In magneto-electric machines it therefore becomes of importance to know what number of cells in series corresponds to the current furnished by the machine. This is ascertained by a means entirely different from that set forth above. The instrument used is composed of similar parts to that described above, similarly arranged, but instead of the rings being made of short thick bands, they consists of long coils of very fine insulated wire. To compare two sources of electricity by this instrument, which is sometimes called an intensity galvanometer, a WOLLASTON'S cell, say, has its poles connected to the binding screws of the galvanometer. This operation, with any cell of ordinary size, will be found to give a considerable deflection, doubtless between 80° and 90°. To make the instrument serviceable it is necessary to reduce the deflection to an angle that can be conveniently read off, but which is small, say 5°. This is done by including in the circuit a resistance, which is conveniently accomplished in the following manner: A stout glass tube, half an inch in diameter and 2 feet long, is completely filled with pure water, long and sound corks being inserted at each end. Through the centre of each cork a stout copper wire is made to pass with friction, so that the wires will remain in any relative position in which they may be placed. It is best to attach a copper disc, of nearly the diameter of the tube, to the end of each wire that is in the tube. By including these wires in the circuit to be tested, and drawing the discs apart until the initial deflection is obtained, the requisite resistance is introduced into the circuit, and this resistance must not be altered during the trial. If the WOLLASTON'S cell be taken out of the circuit, and the poles of a magneto-electric machine, say, be introduced in its stead, the proportional electro-motive force of the magneto-electric machine will be shown by the tangent of the angle of its deflection in comparison with the tangent of 5°. If, for instance, the deflection with the electro-magnetic machine in circuit were $63\frac{1}{2}°$, since tan. $5° = 0·087$, and tan. $63\frac{1}{2}° = 2·000$, the proportion stands 0·087 : 2·000 : : 1 : the number of cells required.

By reducing this proportion it appears that the electro-motive force of the magneto-electric machine is rather less than twenty-three cells of WOLLASTON'S battery. The value, thus obtained, is totally independent of the area of the zinc plate in the cell, or of the size of the cathode that can with advantage be coated by the magneto-electric machine. The relation of area coated by each source of electricity can be ascertained in a similar manner by the quantity galvanometer, taking care to have the minimum resistance in the metallic part of the circuit.

To tell the direction of a given electric current by means of the galvanometer, the following law must be applied:—*The pole above which the current enters is turned to the east, under which to the west.* For instance, in a WOLLASTON'S cell, if the copper plate be connected with the coil or band of metal which passes *over* the needle in the direction from north to south, and the zinc plate with the other extremity of the coil, the north pole of the needle will be deflected towards the east. A serviceable galvanometer for this purpose, and even for estimating electric currents, may consist simply of a compass box placed over a strip of conducting wire that is fixed on a table, or otherwise, in the true magnetic meridian. Numerical proportions, and thence a series of values, in weight of copper deposited per hour, may be assigned to the angles of deflection by direct experiment. When the deflection is small, say below 10°, equal increments of electric power are very nearly indicated by the angle of deflection in degrees, both in this instrument and in the tangent galvanometer.

If, either on the forward or return wire from the battery to the depositing trough, another circuit be established, the current in such a circuit is called a derived current, and it may be made of any given proportion to the main circuit by proportioning the resistance in the derived circuit accordingly. We have used such a circuit to indicate upon a galvanometer at a distance the proportional current circulating, and with the advantage that a small galvanometer could be used at a distance from the operations carried on in the main circuit, in an office many hundred feet from the depositing trough. In such a case it is necessary to provide that the small galvanometer is at least sufficiently far from the main circuit as to be unaffected thereby. The derived current may be used to deposit with, either for experiment or for practical use.

It is important, in using a galvanometer, to deflect the needle both ways, especially when it is fixed for use, in order that the deflection may be precisely ascertained; the instrument should be so placed that the deflections on each side are equal.

Management of Magneto-electric Machines.—These machines are put into action by means of a steam engine or other equivalent motive power, the coils being rotated in the right direction and at the proper speed.

The direction of the current is best ascertained by the galvanometer, care being taken to place the instrument out of the range of the influence of the magnets. The direction depends upon the polarity of the magnets, the direction in which the coils are wound round the cores, and the direction of rotation of the machine. These data are not easily ascertained in a machine which is supplied to the electro-plater ready for use, but if they be, it is well to verify the result arrived at by an appeal to experiment.

The electro-motive force of a machine may be ascertained by the fine-wire galvanometer already described, and the quantity of electricity it is capable of affording in a given time by means of a sulphate of copper depositing cell or a quantity galvanometer. The electro-motive force varies in direct ratio to the speed at which the apparatus is driven. In a machine for depositing upon large surfaces at one time the coils are made with thick wire. Each separate coil in a machine with more coils than one may be looked upon as analogous to a galvanic cell, and the coils may either be coupled together in series or in multiple arc. In the former case, which is rarely required in electro-metallurgy, the positive pole of one coil is connected to the negative pole of the next, and so on throughout the series; in the latter case, all the positive poles are brought to one thick metallic rod in connection with one portion of the commutator, and all the negative poles to another thick metallic rod similarly connected with the other portion of the commutator.

From the principles just enunciated, it will be seen that it is highly important to provide a governor, or other suitable means for keeping the speed of a machine constant. In most large machines 500 revolutions a minute is a suitable speed; small machines may be driven faster. The bearings should be kept cool and well oiled, and the commutators kept quite clean in the cavities between the contact pieces. The insulation of these machines is of even more consequence than in the case of galvanic batteries; all the connections should be carefully insulated, and at a sufficient distance from one another to provide against the touching of conducting wires, &c. To prevent slip of the driving bands, broad bands and band wheels should be used. All the permanent steel magnets should occasionally have their magnetic power tested, and when the machine is out of use their poles should be joined by keepers.

Much that has been explained about binding screws, brightness of connections, and size of wires, applies likewise to any apparatus for generating or inducing electricity, and certainly to magneto-electric machines. These machines should be kept away from acid or other fumes from the depositing room.

Management of Thermo-electric Batteries.—In small machines with gas jets the power is developed soon after the lighting of the gas.

As in magneto-electric machines, the best plan to ascertain the direction of the current from a thermopile is by experiment.

The electro-motive force as well as the depositing power may be ascertained in the same manner as for magneto-electric machines.

Arrangements are usually made for the elements to be coupled either in series, in multiple arc, or in a combination of these methods of working. Binding screws for this purpose are placed in front of the machine.

It is important to keep the heat at or near the same degree; with gas this is easy. The inventor recommends a "cherry-red heat" for the burner of Clamond's battery. A distant fire, or the opening of a window, produces a sensible effect upon a thermo-pile, and when two or more piles are worked together they should be kept as far apart as possible.

The instrument should be placed upon a shelf a little above the head, to enable the products of combustion to be freely carried off.

The points to be observed respecting contacts, connection, and conduction, that have been noticed in relation to galvanic batteries and magneto-electric machines, are also to be attended to in thermo-electric machines.

Modifications of Solutions, and Methods of Working them.—The most usual way of arranging the depositing trough in connection with the source of electricity has been already described; the poles of the galvanic battery are directly connected to the depositing trough. If there be plenty of electro-motive force available, and the contents of a series of troughs are alike, and have to be submitted for a similar time to the operation, the troughs may be arranged in series; the anodes of one trough being connected to the cathodes of the next throughout the series. This plan is not often used, because of the conditions of similarity above alluded to. At first sight it would seem that this method is economical, since, if one battery cell is used, the same consumption of zinc serves to deposit an equivalent weight, say, of copper in each trough; that is, for every 65 parts of zinc dissolved, 63·5 parts of copper are deposited in each trough. Not only is there a limit, however, to the number of troughs that can be employed (for each trough introduces a resistance into the circuit), but the time occupied in the work is increased in proportion, and the quality of the deposit is affected. Moreover, when the electro-motive force is very low, the electric current seems, in small quantity, to pass through the solution without depositing the copper therefrom. According to another plan, if the electric power available be great in quantity, and a number of small troughs are to be worked therefrom, all the anodes may be connected to the positive pole of the source of electricity, and all the cathodes to the negative pole, as in arranging batteries for quantity, that is, in multiple arc. This is a much more practical plan than the arrangement in series, as similarity in the work to be done in each trough is not necessary. By proportioning the resistance in the circuit to each trough, the right amount of electric power may be supplied to it, and the troughs may be of different sizes, and may have various solutions and articles in them. The fine-wire resistance and galvanometer are useful to make these arrangements. Now that electric power can be obtained more cheaply than formerly, and in greater amount, it seems that some such plan as the use of the multiple-arc distribution of electricity is inevitable in large factories. The fourth plan is to utilize the current that has already been described as existing in the derived circuit, proportioning the current thereto by suitable resistances; this is principally available as a test of what is going on in the main circuit, or for small experimental work. The advantage of the derived circuit is that, whatever changes may occur therein, it never interferes with the work in the main circuit.

We have employed with success on a large scale, a method of testing the work done without the disturbance of the arrangement, or of the articles in the vat. This simply consists of attaching by a fine wire to the anode and cathode respectively, strips of the metal that is being deposited, these strips proceeding to the bottom of the bath, and being as nearly as possible the same distance apart as the main electrodes. Sometimes the cathode is of the same metal as the larger cathode to which it is attached; this is advantageous in depositing upon iron.

Copper Solutions—working them.—The solutions to electro-deposit copper are divisible into three classes. Each class depends upon a somewhat different principle for the result produced, and is for the most part to fulfil distinct conditions which the other two classes cannot so well attain. The first class is acid in reaction, and is intended to be used with a separate source of electricity, that is, in a trough that is perfectly distinct from the electric power generated, and which has positive plates or anodes therein that supply the metal as fast as it is deposited. The second class refers to what is known as the single-cell process; in this case the metal is supplied to the liquid by the solution of the salt that is used to make the bath. For this purpose, at the upper part of the depositing trough, in the case of sulphate of copper, pockets or perforated shelves are formed, in which crystals are placed; as the solution weakens by the deposition of the metal, it replenishes itself by dissolving the crystals. The third class is alkaline in reaction; to this class belong Woolrich's* sulphite of potash solution, the ordinary cyanide solutions,† and the ammonio-cyanide solutions.‡

The ordinary acid solutions are prone to deposit their copper in botryoidal masses, instead of evenly, upon the cathode; to prevent this various plans have been tried. Napier uses a small proportion of sulphate of zinc dissolved in the solution; Watts employs arsenious oxide (white arsenic) or chloride of tin; and Walenn recommends an ounce or two of sulphate of zinc to the gallon, combined with a few drops of bisulphide of carbon,§ to be added to the acid cupric solution.

The alkaline solutions are liable to deposit the metal they have in solution as a white precipitate upon the anode, and even at the bottom of the trough; if the oxide of the metal can be kept in solution this great drawback is obviated. For this purpose glycerine‖ may be used, although it makes the solution somewhat less conductive of electricity; another plan is to use about 1 oz. per gallon of the neutral tartrate of ammonium.¶

The battery power required by the acid solutions is comparatively small; one cell of Wollaston's battery may suffice when a separate battery is used; but for quickness of work it is better to use three cells of Wollaston's or one cell of Bunsen's arrangement. When the single-cell arrangement is employed, that is, when a part of the depositing trough is partitioned off by a porous plate for the zinc plate and its solution, this is practically equal to rather more than two Wollaston's cells. For alkaline baths the electro-motive force may range from one to four Bunsen's cells.

The acid solutions have a great tendency to get stronger at the bottom than they are at the top. To obviate this it has been proposed to constantly move the articles in the bath; and although this plan is successful with some solutions, it does not appear to be advantageous in copper solutions. If the article be cylindrical it may be supported in the solution horizontally, and turned round its axis one quarter of a revolution once or twice a day; if it be flat its plane surface should be horizontal; and in all cases the anode and cathode should be near each other in all parts, that is, their cavities and projections should correspond to each other in position.

This peculiarity does not exist in the alkaline solutions, for they are employed in a heated state, and the equable character of liquid that the heat produces, by causing continuous and uniformly distributed circulation, gives an even deposit, and one of good grain. It might be well to try the effect of moderate and regulated heat upon acid solutions; but this plan is somewhat difficult, especially when gutta percha moulds are used in electrotypy. The alkaline cyanide solutions may be worked from 150° Fahr. to boiling point, and it has been noticed that a boiling solution gives a coating that is extremely tenacious and tough.

When a separate battery is used to work an acid solution, the replenishing of the solution with copper is dependent entirely upon the anodes. These should be high up in the liquid, and at least equal in area to the surface of the cathode; they may have double the area of the cathode with advantage. If the deposit is to continue for several days it is advisable to stir the solution once a day; if the strength of the solution has declined, sulphate solution should be added, and if it has increased water may be supplied; this condition may be ascertained soon after stirring, and by means of the hydrometer. The tendency of the solution, apart from evaporation, is to increase in volume if its saturation be kept up by a shelf or shelves containing crystals of sulphate of copper, as well as by the anodes.

In a single-cell arrangement, a number of round porous cells, each containing its zinc plate and acid solution, are often preferable to the above-mentioned porous partition; for the cells can be disposed in the vat according to the configuration of the article or articles which form the cathode. The zinc surface should always be large in proportion to the surface to be coated, and it may be twice as large. Care should be taken that the height of the liquid in the porous cells is the same as that of the depositing solution. NAPIER points out that sulphate of zinc may with advantage be used in the porous cell, care being taken to keep the solution at half saturation.

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* See Specification of Patent, No. 9431 (old law), filed by John Stephen Woolrich, and dated August 1, 1842.

† For probably the first cyanide solution of copper, see Specification of Patent, No. 9077 (old law), filed by Oglethorpe Wakelin Barratt, and dated September 8, 1841.

‡ For probably the first ammonio-cyanide solution, see Specification of Patent, No. 13.216 (old law), filed by Joseph Steele, and dated August 9, 1850.

§ See Specification of Patent, No. 3950, filed by William Henry Walenn, and dated December 24. 1868.

‖ See Specification of Patent, No. 497, filed by Frédéric Weil, and dated February 29, 1864.

¶ See Specification of Patent, No. 1540, filed by William Henry Walenn, and dated June 1, 1857.

In alkaline solutions, the area of the anodes may be as much as five times the area of the cathodes, the heat and the battery power should be kept uniform, and the loss by evaporation should be made up every evening by the addition of a weak solution of cyanide of potassium, about 4 ozs. to the gallon, with stirring. In general, during deposition, alkaline solutions give off hydrogen gas copiously; this may be entirely stopped. For this purpose, if the solution be not of the normal strength, oxide of copper or cyanide of copper may be added, and if this fails or only partially succeeds, strong ammoniuret of copper may be added if necessary, until the solution has a slight green tinge. The advantage of stopping the evolution of hydrogen is at least two-fold: in the first place, it insures non-porosity in the coating; and in the second place, it enables the electric power that had been employed to evolve hydrogen to be usefully occupied in depositing metal, thereby saving electric power. Here it may be remarked that the best method of making ammoniuret of copper is to precipitate sulphate of copper with caustic potash, leaving a slight excess of potash, and add the wet hydrated oxide thus obtained to ammonia-water of specific gravity 0·880, shaking the whole up in a Winchester quart bottle, until the solution is saturated with the oxide. The specific gravity of a cyanide solution may vary from 18° Tw. to 29° Tw. without influencing the deposit obtained. When a solution is working well, the less it is interfered with, except to make up for evaporation, the better. If any crystals have subsided to the bottom of the trough, they should be scraped up and dissolved in ammonia, or if that is impracticable, in nitric acid, and in the latter case the copper recovered by precipitation by a rod of zinc; the ammoniacal solution may be added to the depositing solution.

A single-cell arrangement may be used to work an alkaline solution. The amalgamated zinc in the porous cell must be in contact with an alkaline solution. In this case the solution may be at the ordinary temperature of the air.

For acid solutions, in all small operations, a glass depositing trough is preferable to any other. The material known by the name of stoneware is also very serviceable. For work on a large scale, a wooden vat made in the style of a brewer's vat, and lined with gutta percha, may be used with advantage. For electrotyping large objects, the tank may be built in brickwork, coated with cement and lined with gutta percha.

For alkaline solutions glass or stoneware vessels may be used on a small scale, and copper or iron troughs on a large scale. Some manufacturers use copper troughs, and by connecting them with the copper plate of the battery make them into the anode of the arrangement. This method, however, is false in principle, for there is no means of proportioning the size of the anode to the surface to be coated, and the vessel is continually diminishing in thickness in an irregular manner. The best trough for use on a large scale is decidedly a trough made of wrought-iron plates rivetted together in a similar manner to an ordinary steam boiler, and having a steam jacket provided with a supply steam pipe, and a waste pipe to carry off the condensed water; by this means heat is supplied to the trough, and the temperature can be adjusted with the greatest nicety. Care should be taken not to connect the trough with either battery pole, and as much care should be taken to insulate the depositing trough as to insulate any other part of the circuit. This is often troublesome on account of steam connections, &c.; but a short length, say 6 inches, of strong vulcanized india-rubber tubing, at the place where the steam pipe enters the vat, is amply sufficient to insulate the trough from the steam boiler.

The round porous cells, as well as the porous slabs or partitions, are best made of biscuit ware.

The vat in general should be made of such a proportion as to afford the workman an opportunity of getting to all parts of the trough from one side; that is, supposing that the size of the article to be operated upon permits it. Two feet in depth is convenient; less will do if horizontal electrodes are adopted. The width may be 2 or 3 feet, and the length from 3 to 20 feet.

From numerous experiments tried in 1870 and 1871, WALENN states that he discards three materials as being utterly prejudicial to the formation, from neutral or acid solutions, of a thick homogeneous coating of copper; these are iron salts, sodic salts, and nitric acid, either combined or not. The iron salts, even in small quantity, tend to the formation of pores pure and simple. The sodic salts induce a crystalline structure, the crystals being hemihedral with separated apices; the space between the apices is never filled up. Nitric acid is the worst of all, for it favours the formation of conical nodules that can be picked out, or that fall out, sometimes leaving a space of one-eighth of an inch cube. From an ordinary acid solution, and particularly when considerable electro-motive force is used, the natural condition of the deposit is like that of mortar spread upon a brick with a trowel; the metal appears to be deposited in planes parallel to the surface to be coated, with an inclination to become botryoidal at the edges, judging from thick deposits. From solutions containing positive metals the plane of deposition is turned through a right angle, and the metal is massed together in bundles like the hairs in a hair-brush. This is very noticeable when, with the ordinary acid solution of the sulphate, an excess of zinc salt is present.* 1 or at most 2 ozs. of sulphate of zinc in the copper solution works well, and nullifies the botryoidal character of the deposit; but 4 ozs. to the gallon produces an exaggerated vertical deposit (that is, a series of isolated tufts) which is porous. When bisulphide of carbon is used with 1 oz. of sulphate of zinc to the gallon, a solid silky texture is given, but only if the bisulphide be present in exceedingly small quantity, say a few drops to the gallon; one drop in 10 gals. is sufficient to show the effect, and if the bisulphide be present in large quantity the coating becomes porous.

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* See *Philosophical Magazine*, vol. xli pp. 41-44.

In alkaline solutions of copper two phenomena occur; one is that the deposit is vertical, like the hairs in a hair-brush; the other is that, except especial processes be adopted, hydrogen gas is copiously given off during the deposition of reguline metal.[*] If the means above pointed out be taken to prevent the evolution of hydrogen, namely, the addition of ammoniuret of copper, the coating from the cyanide of potassium solution is bright, without being at all porous; if this means be not adopted, before the coating has become one-hundredth of an inch thick an abnormal deposit is very apparent, and manifests itself in tufts at the corners and edges of the cathode, each fibre of the tuft having a shining button of metal at its apex.

In regard to the speed of the electro-deposition of copper, although it is possible to obtain a thickness of one-eighth of an inch in three days under favourable circumstances, and by using twelve cells of Smee's battery or equivalent magneto-electric force, the coating will scarcely be homogeneous, and it is better to use less electro-motive force, and to take ten or twelve days to do the work.

Silver Solutions—working them.—The use of cyanide of potassium, brought out by Messrs. Elkington,[†] has not been superseded in practice, although (in consequence of its poisonous qualities) many other solutions have been proposed for electro-depositing silver. Nevertheless, some useful variations for specific purposes have since been employed, the difference between these solutions in the proportions of water, free cyanide, and silver cyanide, and also by the addition of other ingredients to the solution being very marked.

Cyanide of potassium enters so much into the practical work of so many operations in electro-metallurgy that this, the first and largest use for it, seems to be a fit place for describing its manufacture. The best way of making it in large quantities is by Liebig's process, which is as follows:—Carefully dried and pulverized ferro-cyanide of potassium (yellow prussiate of potash) is thoroughly mixed with carbonate of potash (also dried carefully) in the proportion of 8 parts, by weight, of the ferrocyanide, to 3 parts of the carbonate. The mixture is heated rapidly in an iron vessel with a cover to it; the heat is continued until the contents melt into a clear liquid, which evolves gas from its surface, and is maintained for about fifteen minutes, until a white sample can be obtained from the molten mass by means of a cold iron rod, and no longer. The vessel may now stand for a few minutes to allow the iron to subside, and for assisting this part of the operation it may be occasionally tapped. The colourless liquid may then be poured off into a cold iron pan, to allow it to solidify by cooling. The white cakes formed in this manner are broken up whilst warm, and preserved in a well-stopped jar. The success of the operation greatly depends upon the iron vessel being kept covered as much as possible; with attention to the above details it is possible to make cakes of this material that contain 80 per cent. of pure cyanide (KCy), although some of the material that enters the market scarcely gives more than 40 per cent. of real cyanide.

The following are some of the proportions of silver solutions, with remarks thereon:—

Name.	Silver.	KCy.	Water.	Remarks.
Elkington (No. 8447), ...	0·16	1·50	160	The first practical solution (oxide of silver).
Napier, ...	1·00	0·62	160	A common method (cyanide of silver).
"	1·00	1·23	160	The electrolytic method (oxide of silver).
De Ruolz, ...	1·29	16·00	160	Used in France (cyanide of silver).
Gore, ...	1 00	1·60	160	Practical method of making a large quantity (cyanide of silver).
Parkes (No. 8905), ...	0·50	8·00	160	Solid deposition (oxide of silver).
Gore, ...	1·00	1·41	160	A good plating liquid (cyanide of silver).

In these proportions the water is placed at 160, because there are 160 ounces to a gallon of water, and the ratios therefore become easy to adopt in practice. The numbers appended to the first left-hand column refer to patent specifications. The second column gives the proportion of metallic silver, and the third column that of ordinary commercial cyanide of potassium. The salt of silver employed to make each solution is noticed in the remarks.

To produce cyanide solutions of silver fit for electroplating, other salts have been used besides the oxide and the cyanide, such as the chloride, the carbonate, and the acetate. When dissolved in the cyanide of potassium these salts become cyanides, leaving in solution the corresponding salt of potassium, which more or less acts as an adulterant, and impedes the perfect action of the solution.

The dead white deposit of silver which is given by the above solutions is not always that which is wanted in practice. A bright deposit of silver,[‡] which does not require manipulation after the article has left the bath, is obtained by adding bisulphide of carbon in very small proportion, and well mixed with the solution. The mixture is made gradually, a gallon of the cyanide solution being first impregnated with a few ounces of the bisulphide, and an ounce or two of this mixture is then well stirred with 20 gallons of the plating solution; about one drop of the bisulphide is thus disseminated in every gallon of silvering liquid.

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[*] See Report of the Meeting of the British Association at Liverpool in 1870—Transactions of the Sections; also *Chemical News* for July 1, 1870, pp. 1, 2.

[†] See Specification of Patent, No. 8447 (old law), filed by George Richards Elkington and Henry Elkington, and dated March 25, 1840.

[‡] See Specification of Patent, No. 11,632 (old law), filed by Morris Lyons and William Millward, and dated March 23, 1847.

The addition of one quarter of an ounce of iodide of potassium to every gallon of cyanide solution is said to insure a complete covering, together with absolute cohesion of the deposited metal to the underneath surface; it gives a durable texture to the deposit.

Three cells of SMEE'S battery is a very good electro-motive force to plate with; this assertion is true for all solutions excepting "bright" solution. One or two cells will suffice for bright solution.

As nearly all silver solutions are worked at the ordinary temperature of the air, there is some tendency in them to become stronger at the lower part than at the top, especially in strong solutions. This is for the most part obviated by stirring them every evening; but it is found quite practicable to adapt machinery to the tanks to move the articles to and fro therein, and thus to equalize the thickness of the deposit and the strength of the liquid. One of the most successful of these arrangements consists of a metal frame upon which the articles are suspended, which has four small wheels that run upon four inclined planes fixed to the edges of the vat; steam power and even clockwork can be used to impart motion to the apparatus. Another obvious arrangement is to suspend the metal frame, that carries the articles, from the roof or from a cross frame, by means of a rope, independent of the vat, and so that vibration can be given to it by means of a crank and connecting rod attached to the shaft of a steam-engine or other prime-mover.

The best uniform temperature for electro-plating is 60° Fahr. In hot weather silver solutions in general are apt to give some trouble; less electric power is then required. If, however, it is desired to simply whiten clock faces, or like articles, very quickly, a weak cyanide solution, containing chloride of silver, may be worked at a temperature of 130° Fahr.; in this case a smaller surface of anode than usual must be used.

Although the single-cell arrangement was originally used to work silver solutions, they are not operated in that way now, for the convenience of the separate battery system is much greater than that of the single-cell plan The surface of the anodes in a trough may be equal to, or even less than, the surface of the articles to be plated. The anodes are mounted vertically beneath the surface of the liquid upon light iron frames.

The general method of managing silver solutions is to stir them every evening after plating. If the depositing liquid requires fresh cyanide, which may be known by the dull yellow-grey colour of the anode, a solution of the potassium salt is added about half an hour before stirring. To ascertain the amount of free cyanide present in a given solution, either LIEBIG'S method, or GLASSFORD and NAPIER'S plan, may be employed.

The depositing vessels for manufacturing purposes are troughs made of a convenient height and width, and any desired length from 3 to 20 feet. Wooden troughs supported on horizontal trussed framing, and lined with lead, are generally used; the framing enables the troughs to be emptied by means of a syphon or otherwise, the bottom of the trough being raised from the floor about 6 inches. The proportion of solution to the area of articles to be coated is from 7 to 10 gallons to every square foot.

To some extent the principal varieties of metal that silver solutions afford have been set forth. To preserve a solution in a uniform state from time to time, even working and a constant electric power are necessary; in this way a solution may last for years. The ordinary dead silver may be deposited hard by using eight or nine SMEE'S cells, or an equivalent electro-motive force; ordinarily it is soft, and its dead appearance may be removed by scratch-brushing. The metal produced when bisulphide of carbon is added to the liquid to form "bright" solution has very much the appearance of fused metal. If an article be removed and replaced, it may or may not receive a bright deposit; even the disturbance of the solution may cause the brightness to cease. The smoothness and brightness commences at the upper part of the cathodes; it then appears at the lower part and the two portions meet. Similar effects have been observed in other departments of electro-metallurgy.

The average rate of deposit of silver is about 1½ oz. of silver per square foot in a day of about seven hours; it may, however, for certain purposes, be deposited at four times this rate, and yet give a reguline coating.

Gold Solutions—working them.—The use of cyanide of potassium as the menstruum or solvent solution for dissolving gold which is afterwards to be electro-deposited therefrom is due to Messrs. ELKINGTON, and, like the silver solution, has never been superseded.

Other salts besides the cyanide may be dissolved in cyanide of potassium to form the electro-depositing liquid, notably the oxide, the ammoniuret, and the hydrosulphate as thrown down by hydrosulphate of ammonium. The oxide may either be thrown down from the trichloride by caustic potash, by magnesia, or by zinc oxide; in the latter case the zinc can be separated by nitric acid. The ammoniuret is formed by precipitating the gold with ammonia; this compound explodes when heated to 212° Fahr., or when struck upon an anvil with a hammer.

An electro-motive force equivalent to four of SMEE'S cells will work a gilding solution when it is heated to 130° up to 150° Fahr. One cell will suffice if the solution be worked at boiling point.

Upon the first immersion of the articles to be gilt, they may be moved about with advantage; they may be allowed to rest for the remainder of the process.

All gilding solutions require to be worked hot, the temperatures varying from 130° Fahr. to boiling point. The heat may be supplied either by a stove, by gas jets, or by boiling water.

In electro-gilding especial care must be taken to have electrodes of equal area. The amount of free cyanide in a given solution may be ascertained by means of ammonio-sulphate of copper. Every night the amount of evaporation during the day must be made up, ready for the next day, by the addition of distilled water to the liquid. The anodes used in the depositing trough should be entirely immersed in the liquid; they may be supported by platinum conductors.

Glass and earthenware vessels may very well be used for electro-gilding. An iron pan, enamelled in its interior, is useful for working on a large scale.

The varieties of metal, to outward appearance, that electro-gilding solutions afford are rather numerous. The addition of a little ammoniuret of gold to the liquid just before the articles are immersed gives them a deep rich orange colour. When the precipitate that is dissolved in the cyanide solution, during the manufacture of the gilding solution, is formed by adding protosulphate of iron to the trichloride solution, a rich colour is produced, but more yellow than that described above. The addition of bisulphide of carbon to a gilding solution causes it to deposit bright metal. By regulating the heat of a gilding solution, and by charging it with a small and ascertained amount of copper from a large anode, several varieties of colour may be obtained in the deposited metal.

It is important to observe cleanliness and orderly working in operating with gold solutions; uniform results are insured thereby, and saving of gold is effected. A few minutes' immersion of the article suffices for ordinary purposes, but it is in all cases highly necessary to ascertain by weighing the amount of gold deposited; otherwise, it often happens that a deposit which we think will last for years disappears in a comparatively short time.

Brass Solutions — working them. — The ordinary solutions for throwing down brass by means of electricity, including those mentioned under the head of Solutions for Electro-depositing Metals, require considerable power, and only throw down a film which does not exceed one-hundredth of an inch in thickness under the most favourable circumstances. Nevertheless, the examples given are the best of their class. Although very difficult to manage, they are more constant under work than many others; but unless they are continually attended to are liable in constant working to deposit copper only or zinc only, and that generally in some abnormal form. For producing the same coloured brass under the same conditions, they can only be used by an experienced hand. Sometimes in large flat surfaces, or in the hollows of ornaments, an ugly dark green streak will commence at the top, and soon after another from the bottom; this condition can only be alleviated by almost making the solution over again. At other times the streak is of a brick-red colour. Strong ammonia added freely will, however, effect the requisite correction in some instances; but this cannot be added while the solution is hot. A little cyanide of potassium solution may also be added.

Walenn has described a certain class of solutions for electro-depositing brass, and the means of preserving them in good condition under working, which he states produces thick deposits of uniform colour. A solution discovered in 1857 fulfils some of these conditions, but is not perfect; it however paved the way for a more practical result in 1868.* By the latter method, or rather by the two methods in combination, he states that a thick and uniform coating of reguline brass can be deposited by means of comparatively small electric power.

The solution which comprises the first invention has the following materials and proportions by weight:—

Cyanide of potassium (commercial),........	1 lb.
Tartaric acid (in powder),....................	12 ozs.
Ammonia water (specific gravity ·880), about	10 "
Water, about...............................	1 gal.

The cyanide is to be dissolved in half a gallon of water in one vessel, and the tartaric acid is dissolved in one-third of a gallon of water in another vessel; at least as much of the ammonia water is to be added to the tartaric acid solution as will neutralize it. The ammoniacal solution is then to be added to the cyanide solution, the whole made up to 1 gallon by the addition of water, and the mixture charged with brass by means of two or three Bunsen's cells in connection with a large brass anode, until a good deposit is obtained on trial, heat being gradually applied as the process of charging proceeds. Good yellow brass should be deposited at a temperature of 130° Fahr., with but little evolution of hydrogen when a single Bunsen's cell is used. It is important to notice that the neutral tartrate of ammonia, which is a constituent portion of the above mixture, is not the tartrate of ammonia of commerce; the tartrate of ammonia of the shops is acid tartrate, and the addition of this salt to the cyanide of potassium would be the surest way to charge the apartment in which the mixture took place with hydrocyanic acid gas, thus wasting the materials and poisoning the manipulator. With only ordinary attention this solution will deposit a thickness of uniform brass of three-hundredths of an inch, without any signs of deterioration.

The second invention consists mainly of a method of stopping the evolution of hydrogen gas during deposition; this he conceives to have been the bane of all ordinary electro-brassing solutions, since, as the bubbles of hydrogen gas are electro-deposited upon during their progress away from the cathode, they produce channels or pores that in many cases occlude a portion of the solution, and cause exudation in spots upon the surface of an article hours after it has been finished. In order to make up for the waste of electric power in evolving hydrogen as well as depositing questionable metal, a considerable electro-motive force is required to do the whole work. The evolution of hydrogen being stopped, the metal may be deposited to any thickness. Good work can be done with a single Wollaston's cell. No spots or stains appear on the work after it is finished. To effect this desirable result (namely, stopping the evolution of hydrogen gas), the best way is to take 1 part by weight of zinc oxide and 2 parts by weight of oxide of copper, placing them in separate vessels; ammonia water is added to each, so as to dissolve them, and the two solutions are mixed. The addition of this compound in the cold to the solution described as the first invention, prevents the evolution of hydrogen therefrom during deposition; if necessary, sufficient of the ammoniacal solution may be added to make the original solution green in colour. This second invention also comprises a solution which is compounded as follows:—

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* See Specification of Patent, No. 3930, filed by William Henry Walenn, and dated December 24, 1868.

Cyanide of potassium,	1 lb.
Sulphate of ammonia,	1 "
Nitrate of ammonia,	1 oz.
Water,	1 gal.

The above forms the solvent solution to be charged with brass by the electrolytic method. The cyanide of potassium and the sulphate of ammonia should be dissolved separately in half a gallon of water. When perfectly dissolved they are mixed in the cold and the nitrate added thereto; or the nitrate is dissolved in a separate portion of water, and its solution added to the main solution. The above may be heated during charging. If required, the previously described ammoniacal compounds of zinc and copper may be added to this solution to stop the evolution of hydrogen during deposition.

Another portion of the second invention refers to the employment of a single-cell arrangement in the electro-deposition of brass, an alkaline salt being used to excite the amalgamated zinc plate. This combination has produced good thick deposits of brass from cold solutions.

In many of the ordinary and old brassing solutions the least change of battery power, of heat, or of the mechanical condition of the liquid by stirring, or taking out an article therefrom, is likely to cause a change of colour in the brass, and may cause either zinc or copper to be thrown down instead of brass. Walenn states that in the above solutions a small change of electro-motive force, or of the relative area of the anode and cathode, does not alter the character of the deposit; although there is some latitude in respect to heat, the alteration of the heat of the solution may properly be used to regulate the colour of the brass. At low heats the brass is yellow, and is still yellow up to about 130° Fahr.; golden tints succeed, then red brass at boiling point.

The battery power used in ordinary brassing solutions is two cells of Bunsen's or from six to twelve cells of Smee's construction. For the new solutions just described, Walenn considers that one cell is quite sufficient, though it is better to use three of Smee's cells to economise time. If less than three Smee's cells are used with ordinary brassing solutions, brass is not deposited, but only copper or zinc.

The effect of motion upon electro-brassing liquids has been already mentioned. When employed in conjunction with a brisk heat and plenty of battery power, it may be used to correct a solution. If a solution manifests the slightest disposition to abnormal deposits, its resuscitation should be taken in hand at once, or it may never be recovered.

Heating a brass solution is not only the means of regulating the colour of the deposit, but it enables the anode to dissolve with sufficient speed, and without being impeded by insoluble saline precipitates.

In general, a brass solution will bear a considerable amount of evaporation without its work being altered thereby, say from 18° Tw. to 30° Tw. When the volume of a solution has to be made up after use, the addition of water thereto would precipitate some of the salts; the best mixture to add is one containing 4 ozs. of cyanide of potassium and 2 ozs. of strong ammonia to the gallon. In ordinary solutions the area of the anode should be at least six times the area of the cathode; in the above described new solutions twice or three times the area is quite sufficient. In the single cell arrangement above alluded to, the oxides of the metals, dissolved in ammonia, are supplied from a tall porous cell. All brass solutions should be worked in an apartment that has a free circulation of air.

The best vessel on a large scale for electro-brassing is undoubtedly a wrought-iron trough rivetted together, and having an external steam jacket. On a small scale, a sand bath, together with a stoneware or glass trough, may be used with advantage. In cases where heat is not required, a glass or porcelain trough may be employed.

The quality of metal given by ordinary electro-brassing solutions is almost a misnomer; it is generally a skin of exceedingly hard and brittle metal. The presence of free ammonia or of ammoniurets of the metals in the solution tends to make the coating less brittle; the same result is attained if the solution will bear a high heat. * "The general characteristic of electro-brassing solutions, when in good order, is to deposit the metal in needles at right angles to the surface, more or less detached from one another, according to the state of the solution and the electric power employed. This peculiarity can be traced to the fact of alkaline solutions being used for this purpose, the metal of the alkali being prone to be deposited (for an infinitely small duration of time), together with the heavy metals, and to the hydrogen copiously given off during deposition." The character of the deposit is strongly seen if considerable electro-motive force be used, and the coating be

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* See *Philosophical Magazine*, January, 1871, p. 42.

continued for some time. The latter operation is not an easy matter with ordinary solutions, partly because of the formation of an insoluble and non-conductible coating on the anode, and partly from the tendency of ordinary brass solutions to deposit a sandy dust upon the top of the reguline coating, after a time; the formation of the latter can to some extent be obviated by adding a portion of the solvent solution to the depositing solution. It is to be remarked that the solvent solution of a given depositing solution is the solution without the metals that are to be deposited therefrom.

In the new solutions the quality of metal is almost identical with that produced by Napier's modification of the normal sulphate of copper solution. With low electro-motive force, or with the porous cell plan already described, the metal is fairly soft and tough; to deposit hard metal, a high electro-motive force is requisite.

Bronze Solutions—working them.—A true bronze, (that is, a veritable alloy of tin and copper) can be electro-deposited from many of the brassing solutions when tin is substituted therein for zinc. In general, they are even more difficult to manage than brassing solutions, for besides all the peculiarities of the latter, the tin salt is not so easily soluble in the menstruum as the zinc salt, and has a great tendency to deposit upon the anode in the form of a compact non-conducting layer, thus tending to stop the electric current, producing non-reguline deposits and exhausting the liquid.

A deposit of pure bronze, one thirty-second of an inch thick, can be obtained from a solvent solution containing cyanide of potassium and neutral tartrate of ammonium of the same strength as that used for brass; but instead of equal parts of these salts, as in the brass solvent solution, the salts should be in the proportion:—

Cyanide of potassium, ...	6 parts.
Tartrate of ammonium, ...	1 "

and the solution should be charged from a bronze anode, or from an anode formed of the two metals, tin and copper, clamped together. Much of the bronze at present produced upon iron is simply an oxidized copper deposit of extreme thinness.

Speculum metal is an alloy containing copper, tin, zinc, and silver; this has been deposited, from the tartrate and cyanide solutions, in proper proportions and beautifully polished. Walter Jones, of Wolverhampton, was the first to prove the capability of this solution to electro-deposit this complicated alloy, which he did upon a brass speculum previously fashioned.

The electric current used for bronzing is about the same in kind and degree as that employed in brassing.

For the most part bronzing solutions are heated, but we have successfully used the tartrate and cyanide solution cold.

The only way in which bronze solutions have been kept of the same quality is by means of an anode of the kind of metal to be deposited, or by means of a compound anode of copper and tin, in which the surfaces exposed are in the ratio of the weights of the components of the reduced alloy.

The depositing vessels or vats may fitly be of the same materials, and similarly arranged to those already described for brassing.

The metal, when deposited in proper form, is of similar structure to the brass deposit.

German Silver Solutions—working them.—The solution that is given under the head Solutions for Electro-depositing Metals is worked in a similar way to brass solutions, and has similar peculiarities.

Iron Solutions—working them.—Besides the solutions given under the head devoted to the description of methods of making solutions, it has been stated that a good deposit of iron upon engraved copper plates is obtained from Joubert's invention, in which chloride of iron is the salt employed.

According to Walenn the most serviceable solution to electro-deposit iron upon copper is a solution of ferrous sulphate containing sulphate of ammonia.* The addition of sulphate of ammonia lessens the evolution of hydrogen from the electrolysis of the sulphate only. Ferrous sulphate (slightly acidulated) is remarkable as being an exception to Smee's laws respecting the quality of the metallic deposit, when hydrogen gas is evolved during deposition from a metallic salt. Although with three Smee's cells hydrogen gas comes off from the above (acid) solution of ferrous sulphate in copious volumes, the deposit has a white silvery appearance.

Another solution for electro-depositing iron, to protect copper plates during printing, is made by electrolyzing a solution of chloride of ammonium for a certain time with a large iron anode.†

With the double sulphate of ammonia and iron solution three cells of Smee's can be used with perfect success. The solution of iron in chloride of ammonia is said to require from fifteen to twenty cells of Smee's, or five pairs of Bunsen's arrangement, to work it properly.

All iron solutions are worked at the natural temperature of the air.

There appears to be no difficulty in supplying the solution with metal by means of an iron anode.

The depositing vessel may be of glass or stone ware.

The quality of metal reduced from any solution of iron is well worth study. It is of a bright silvery lustre, not so liable to tarnish as ordinary iron, and is exceedingly hard. Its texture is like a good deposit of brass, or like the hairs of a hair brush; all iron deposits by electricity have this characteristic strongly developed.

Nickel Solutions—working them.—The ammonio-chloride of nickel is said to yield good metal when electrolyzed by two of Grove's cells.‡

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* See *Chemical News*, vol. xvii. p. 170.

† See Specification of Patent, No. 667, filed by Edmond Auguste Jacquin (a communication from Henry Garnier), and dated March 29, 1858.

‡ See Specification of Patent, No. 3125, filed by William Brookes (a communication from Isaac Adams), and dated October 28, 1869; also *Chemical News*, vol. xxvi. p. 209.

A moderate battery power may be successfully used to electro-deposit nickel. It is not necessary to use heat in order to reduce the metal.

One of the difficulties that, until a comparatively recent period, have prevented the introduction of this beautiful deposit into ordinary use, is the obtainment of the metal in a suitable form to act as an anode, nickel being exceedingly difficult to fuse, and very brittle when cast into plates. We believe that this difficulty has been overcome by combining the nickel with carbon, and it appears that a combination of nickel and iron has been successfully used.

The vats may be the same in material and construction as those used for depositing copper from its acid solution.

The quality of metal is hard, compact, and somewhat silvery in appearance; nickel is deposited with ease in a bright form. The metal is not prone to tarnish.

Platinum Solutions — working them. — The metal platinum is exceedingly difficult to deposit in a reguline form, owing to its tendency to assume the condition of a black powder. We have been informed, however, that by means of a solution of nitro-hydrochloric acid, only depositing the metal as fast as it comes into solution, a good deposit may be obtained.

A very weak electric force is required, and the solutions are generally heated.

Except in the nitro-hydrochloric acid solution, it is not easy to keep platinum solutions properly charged with metal. The usual plan is to supply chloride of platinum from time to time.

In the case of the nitro-hydrochloric acid solutions the vessel must be of glass or stoneware, so as to withstand the action of the acid.

To deposit the black powder of platinum it is simply necessary to electrolyze an acid solution of the bichloride. The nitro-hydrochloric acid solution may possibly be used to thicken a coating already given to iron (for instance) by the alkaline solution already described under the head Solutions for Electro-depositing Metals.

Tin Solutions — working them. — All the stannate solutions of tin are prone to precipitate a compound of the metal in an insoluble form. If the solution is very weak and contains cyanide of potassium, no stannates can be formed, and the metal can be thrown down easily in the reguline form upon iron and other metals.

The battery power for ordinary tin solutions may be moderate, but for the weak solution just described it must be weak.

The ordinary solutions of tin are worked cold, but one that contains soda, potash, and cyanide of potassium is heated to 75° Fahr.

The tin is supplied to the solution by means of an anode of sufficient size.

On the large scale the vats may be the same as those for electro-depositing silver. The solution that is to be heated may be worked in a wrought-iron vessel with a steam jacket.

The deposit of fine white reguline tin is a matter of some difficulty. From the chloride, tin deposits in long crystalline needles, and the resulting deposit has a fern-like appearance of considerable beauty.

Zinc Solutions — working them. — Having worked with the sulphate solution, the making of which has been already described, we can recommend it for coating iron. Other solutions are known, especially one containing cyanide of potassium, ammonia, and carbonate of potash, which is said to give good results in coating iron and steel.*

To work the first solution, a single cell of WOLLASTON'S battery is sufficient, but two or three cells may be used. The cyanide solution requires two BUNSEN'S cells, and more than this power may be employed to save time.

The motion of articles in the latter solution assists deposition.

Both these solutions are worked cold.

The sulphate solution is replenished by means of anodes of good rolled zinc of sufficient area. This solution can be worked continuously, and is one that gives no trouble in respect to insoluble precipitates or deposits of an abnormal character. The cyanide solution is worked with zinc anodes; if the solution, from being worked with too small a surface of anode or from other causes, becomes deprived of its zinc, it may be charged with zinc by the electrolytic method, using a porous cell containing cyanide of potassium solution to receive the negative electrode.

The deposit from the sulphate solution is of the most perfect kind, not botryoidal and not in needles. The cyanide solution deposits vertically, but gives a perfectly coherent coating.

Palladium Solutions — working them. — The cyanide solution already given deposits good metal in a satisfactory manner, but there are two other solutions published; the first† contains chloride of sodium, alum, and cream of tartar; the second‡ is compounded of chloride of sodium and boracic acid, or chloride of sodium and tartaric acid.

A moderate electric power suffices for the cyanide solution, which is used cold.

A palladium anode may be used with confidence to produce reguline metal, as the solution acts upon the anode with great energy, and conducts freely. The management of this solution is easy.

Any depositing vessel that can be used with cyanide solutions may be employed in this case.

The quality of metal from the cyanide solution is said to be very good, and able to be deposited to any thickness in a reguline form.

Cadmium Solutions — working them. —The method given under the head Solutions for Electro-depositing Metals is said to be satisfactory. The strength of it may vary.

This solution is worked with a moderate battery power, at about 100° Fahr., and with a plate of cadmium as an anode.

* See Specification of Patent, No. 2721, filed by Alexander Watt, and dated December 3, 1855.

† See Specification of Patent, No. 9077 (old law), filed by Oglethorpe Wakelin Barratt, and dated September 8, 1841.

‡ See Specification of Patent, No. 9786 (old law), filed by Oglethorpe Wakelin Barratt, and dated June 15, 1843.

Aluminium Solutions—working them.—There are several cyanide solutions of this metal. In one case the hydrate of alumina is dissolved in the cyanide by boiling;* in another instance, alum is added to the cyanide, and dissolved by boiling; in a third plan, solutions of alum and salts of tartar are similarly combined with cyanide of potassium; in a fourth method, the depositing solution contains hydrate of alumina, salts of tartar, and cyanide of potassium; and the ingredients used to form another solution are carbonate of potash, alum, cyanide of potassium, and carbonate of soda.†

A single-cell arrangement may be used to work the pipe-clay solution already described under the head Solutions for Electro-depositing Metals, or other equivalent electric power. To work the cyanide solution, an electric current of considerable electromotive power is required.

The pipe-clay solution is used hot; it appears that the cyanide solutions may be used cold.

The pipe-clay solution is best resuscitated by boiling the acid with the solid ingredients. The cyanide solutions may be worked either with an aluminium anode, or by an anode of platinum and a bag of alumina to replenish the solution.

Glass or earthenware vessels may be used to deposit from the pipe-clay solution, and suitable vessels to deposit from the cyanide solutions.

From the acid solution a fine white deposit of aluminium is obtained. The quality of metal produced by the alkaline solution is probably analogous to other metallic deposits from similar solutions, such as that of copper, but its precise form is not stated. Methods of depositing various alloys of aluminium are described together with the cyanide solutions.

Silicium Solutions—working them.—According to a patented invention silicic acid is dissolved in a solution of carbonate of soda by boiling, and to the dilute liquid is added 3 per cent. of carbonate of ammonia.‡

The method of making a solution of silicium by means of hydrofluoric acid has been described in the proper place; this may be worked with three or four pairs of Smee's cells. or by the single-cell process. The electric power most suitable for the alkaline solution is not stated by the patentee, but it is probably similar to that required for other alkaline solutions of the metals.

The acid solution is employed hot; the alkaline solution is heated to between 30° and 40° C., or 86° and 104° Fahr., during use.

The acid solution may be replenished by boiling with the solid ingredients. The alkaline solution is worked with an anode of platinum, and its strength is kept up by a small bag full of the metallic salt immersed therein.

Glass vessels cannot be used to contain the hydrofluoric acid solution, as they would be attacked by the acid, but platinum or leaden vessels may with safety be employed. The patentee uses vessels of wood to contain the alkaline solution, but it might evidently be better placed in an iron vessel.

The metal yielded by the acid solution is said to be a good white deposit of metallic silicium.

Antimony Solutions—working them.—George Gore of Birmingham has made the subject of electro-deposited antimony entirely his own, and has published results of a practical nature, as well as of a remarkable character, relating thereto.§ By far the best solution that this indefatigable investigator has tried may be made by mixing together:—

Potassio-tartrate of antimony,..........	8 lbs.
Hydrochloric acid,......................	4 "
Water,..............................	2 "

A weak battery power should be used with the chloride, but the potassio-tartrate solution will bear a very great amount of battery power without the deposit passing into the state of a loose powder.

It does not appear that heat is used with the two solutions that have been selected for description here, namely, the chloride and the hydrochloric acid solution of the potassio-tartrate.

As both of these solutions conduct freely, they can be easily worked with an antimony anode.

Glass-depositing vessels may be used, or any vessel that will resist hydrochloric acid.

When deposited slowly the metal has much the appearance of highly-polished steel. When the metal is deposited rapidly it is liable to fracture upon being rubbed with any hard substance; the fracture is accompanied by an explosion, during which a small cloud of white vapour appears, and light and heat are developed.

Bismuth Solutions—working them.—The bismuth solution (described in its proper place) requires an exceedingly feeble current to deposit it in a reguline state; its appearance when so deposited is very beautiful, white with a faint pinkish tint, and with a fine silky lustre.

Cobalt Solutions—working them.—For the electrolysis of the alkaline chloride a very weak electric current is used.

Lead Solutions—working them.—A weak solution of either acetate or nitrate of lead may be used for the purposes of electro-deposition.

The batteries used for the caustic potash solution (already set forth) are charged with caustic soda or potash. To work the acid solutions only moderate electric power is required.

Either of these solutions may be used at the ordinary temperature of the air.

The alkaline solution may be kept charged with lead to some extent by means of an anode of the metal, but our experience with similar solutions leads us to infer that the tendency of this class of solutions is to throw down an insoluble precipitate on the dissolving plate. In this case the only way to resuscitate a solution that is weak in metal is to boil the metal or its oxide in the alkaline solution. It is possible that when other metals, such as zinc or tin, are in the same solution as the lead anode, or in contact with it, as proposed in one instance by the inventor, the solubility of the anode may be increased. There is not so much difficulty in supplying the acid solutions with metal.

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* See Specification of Patent, No. 2724, filed by Frederick Samson Thomas and William Evans Tilley, and dated December 26, 1854.

† See Specification of Patent, No. 2756, filed by Frederick Samson Thomas and William Evans Tilley, and dated December 6, 1855.

‡ See Specification of Patent, No. 1183, filed by Claude Joseph Edme Junot (a communication), and dated December 28, 1852.

§ See *Philosophical Magazine*, vol. ix. p. 73; *Pharmaceutical Journal*, vol xv. p. 413; Philosophical Transactions, 1858, p. 185; 1859, p. 797; and 1862, p. 323.

Iron tanks, or tanks of any material that will withstand the action of alkalies, may be used with the alkaline solution, but the acid solutions require non-metallic vessels.

The quality of metal from the acid solutions is said not to be very serviceable; that from the alkaline solution seems practical.

Tungsten, Molybdenum, Chromium, and Titanium Solutions—working them.—These solutions are worked almost exactly in the same way as the alkaline solution of the metal silicium, already treated of.

Thallium Solutions—working them.—Platinum terminals have been used to precipitate the metal from its sulphate.

In concluding this portion of the subject it is important to remark that absolute cleanliness of vessels to contain solutions, and of all other appurtenances in the electro-plating factory, is an item of great consequence, and requires constant attention. Chemical cleanliness, in the strictest sense of the word, should be aimed at, and this requires a plentiful and convenient supply of pure water, together with sinks, cloths, and brushes, suitably placed. For want of due attention to this matter, many solutions are spoiled or lowered in quality. If possible, distilled water, and certainly filtered water, should be used for acid copper solutions and for cyanide solutions, otherwise an insoluble precipitate falls to the bottom of the trough. A serviceable filter may be made of thick flannel or fearnought, a frame of wood being made to keep the mouth open, and to fit the top or a part of the top of the depositing trough. Some solutions, such as those used to copy copper plates by electrotypy, should have glass or other serviceable covers over them, and an iron cover to the copper cyanide solution may be employed with great advantage and economy. When a solution is made and works well it should be altered as little as possible. Besides cleanliness, the other watchword of success, both in adherence to rules and to numerical relations, is exactness.

APPLICATIONS OF ELECTRO-COATING METALS.—Having defined the objects and purposes of electro-metallurgy, and given a general view of the method of working, together with the methods of making and working solutions, and the nature of the power to be employed in practice, it now remains to treat of the applications of the art. In respect to electro-coating metals, the general principles to be borne in mind are, that the metal to be coated must be absolutely clean, and must expose a pure and perfect metallic surface to the solutions employed; that the proper solution be selected to give the required result; and that the finishing processes be efficiently and suitably performed, especially considering that the final appearance and serviceable character of the work done depends in great part upon the kind and degree of finish that the process is designed for, and that the article is capable of receiving.

Electro-plating.—This generic name is given to the art of electro-coating German silver, and other similar metals, with silver or gold, to stand in the place of solid silver or gold articles.

In electro-silvering the electrodes from the source of electricity are suitably connected to brass rods that proceed across the vat, one set of rods being connected to the light iron frames that carry the silver anodes, and the other set serving to carry the suspending wires that are attached to the articles, the wires being clean and tightly wound several times round the rods. Either sheets of silver or cast plates may be used as anodes.

In electro-plating household plate some manufacturers heat the article sufficiently hot to decompose any grease that may be upon it, then scratch-brush it with stale beer, and wash it in cold water that has been boiled. Whilst in the water, and with wet fingers, the suspending wire (from 12 to 20 inches long and one-thirty-second of an inch in diameter) may be adjusted. Spoons and forks are hung upon top frames shaped like gridirons, and subjected for the requisite time to the action of the depositing bath. If a strong coating be required the articles may be removed from the bath after a few hours' immersion, again scratch-brushed, and returned to the bath for the remainder of the time. After being coated the article should be plunged into hot water, scratch-brushed with beer, washed with hot water, and placed to dry in hot boxwood sawdust.

This plan will answer for cruet frames, candlesticks, and other similar articles of German silver.

Instead of the direct application of heat to drive off the grease, a boiling alkaline solution is sometimes used; this may consist of 1 lb. of caustic potash to the gallon, and it is best used in a wrought-iron steam-jacketed trough with a counter-balanced cover to it. The solution should have some slaked lime in it to keep the alkali in the caustic state. The article is then washed in water, immersed in weak nitric acid, washed, dried, dipped in strong nitric acid, again thoroughly washed, and immersed in the silver solution, from which it is taken after a few seconds, examined, and well scratch-brushed; this examination is particularly necessary with a new solution.

For large articles, if made of copper, brass, or German silver, some electro-platers substitute a weak solution of nitrate of mercury for the nitric acid cleansing solution.

Britannia metal, pewter, and alloys of lead and tin, should be plated in a solution containing much free cyanide, and with a large surface of anode.

Iron and some other base metals, such as lead, zinc, and tin, may be successfully prepared for plating by first electro-coating them with copper or brass by means of one of the cyanide solutions.

To merely whiten a clock dial, a few minutes in a hot but dilute silver solution is requisite. The heat may be 130° Fahr. When coated, the dial should be plunged into boiling water and allowed to dry spontaneously.

If the silver does not adhere to the underneath metal in any case, it may be necessary to remove it (or "strip" it); this may be done by means of hot oil of vitriol containing some nitrate of potash. Another plan is to make the article the anode in the plating bath; a solution containing excess of cyanide may be kept for this purpose.

Steel pens, fish hooks, hooks and eyes, and other very small articles, are suspended in a moving cage of copper or silver wire.

Different metals should not be coated at the same time in the same bath. It is best to preserve one bath for each class of work. A "bright" solution should be carefully worked, and should not be overcharged with bisulphide of carbon.

The process of gilding is often applied to silver articles, or to work coated with silver, care being taken that the metal is clean according to one of the methods already set forth. A coating of brass forms a very good basis for electro-gilding. If there be any pewter solder on the article to be coated, Watt recommends that a single drop of acid solution of sulphate of copper be placed upon the solder and copper precipitated thereon, by touching it with steel wire.

A copper anode in a gold solution is used sometimes to gild cheap jewellery, the solution being supplied with gold from time to time.

A thin film of electro-deposited gold is sometimes used to impart tone to daguerreotypes.

Electro-gilding has been successfully applied to the balance springs and balances of watches, and to the pivots of mariner's compasses; also to render the locks of burglar proof safes acid proof, and to line chemical vessels.

After gilding, the article is thoroughly rinsed in hot water, and dried in hot boxwood sawdust.

Copper and its Alloys, Deposition of, upon Iron and Zinc.—It is important, in the hot cyanide solutions that are used, to be careful not to allow either of the electrodes to have metallic contact with the metal of the bath; also the binding screws should be placed out of the way of the steam from the solution. A wooden rim fixed round the top of the bath facilitates these arrangements, and provides for the fixing of the anodes in a long bath.

In coating the cast-iron ram of a hydraulic press in the coppering bath, it was carefully turned, its surface was finished in the lathe without the use of oil, and then protected by clean canvas bags. The ram was about 29 feet long and 10 inches in diameter, and was taken on two railway trucks (one at each end) from the lathe to the depositing trough along a railway of some 30 yards in length, being delivered over the bath. Pulley blocks then raised the ram, the trucks were removed, and the ram lowered into the hot solution. This solution, which was composed of cyanide of potassium and tartrate of ammonium in the proportions already given, was highly alkaline, and was allowed to act upon the ram as a cleansing solution for about half an hour; the negative electrode of a powerful magneto-electric machine was then connected with various parts of the ram by means of copper rings (shifted from time to time), and the deposition was allowed to take place for two days. At the end of this time considerably over one thirty-second of an inch of good serviceable copper was deposited, and the ram was removed and washed.

Axial rotation was imparted to the ram continuously, but it is quite a question whether it was necessary to do more than rotate it through one-fourth of a revolution every three or four hours.

In the year 1873 a plan for coppering ships was proposed.* According to this plan the dock containing the iron ship is composed of granite blocks, the joints being filled in with bitumen; chambers of caustic alkali are connected with the dock, a porous septum being between. The zinc plates that form the single cell arrangement, by means of which the coating is accomplished, are placed in the chambers. The preparatory bath contains:—

Caustic soda,..............................	100 lbs.
Rochelle salt (tartrate of potash and soda)...	300 "
Water,..................................	218 gals.

When the preparatory or cleansing bath has done its work this is pumped out from the dock, and the coppering solution is admitted. This contains:—

Caustic soda,..........................	160 lbs.
Rochelle salt,..........................	300 "
Sulphate of copper,..	70 "
Water,.................................	218 gals.

After a thin coating from this solution the coating may be completed by the ordinary acid sulphate solution. The caustic solution of the zinc cell may be regenerated.†

There are many difficulties in carrying out any plan for electro-coppering vessels; doubtless those of construction and manipulation may be overcome, but the fundamental objection remains that sea-water destroys electro-deposited copper with great energy.

Wrought-iron work, in the shape of tubes, rods, and other ordinary forms suitable for engineering purposes, can be coated with copper, for the sake of preservation, much easier than cast iron. The outer skin of protoxide of iron is removed by pickling the article in weak sulphuric acid, taking care that the pickle is not allowed to act longer than is absolutely requisite, and removing all stubborn parts with a file, or hammer and chisel. The pickle consists of 1 part of oil of vitriol and 20 parts, by measure, of water. Before placing the article in the hot cyanide coppering bath, the pickle should be thoroughly removed by scrubbing with sharp sand

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* See Specification of Patent, No. 3136, filed by Frédéric Weil and Farnham Maxwell Lyte, and dated September 25, 1873.

† To precipitate the zinc, sodic sulphide may be used: see *Chemical News*, vol. xiii. p. 1.

and plenty of water. If the article be large, and some time must necessarily elapse between the scrubbing and the immersion in the bath, the plate may be effectually preserved from superficial rust by being well scrubbed with some of the depositing solution, or in practice, some carbonate of soda solution may be used. Before connecting the electrodes with the trough arrangements the article should be allowed to remain a sufficient time to get to the same heat. If the alkaline deposit is to be succeeded by a coating from an acid solution, great care should be taken to clean the article thoroughly with plenty of sand and water from all traces of the alkaline solution; if possible it should be submerged in pure boiling water for this purpose. If any signs of porosity, such as dark-coloured spots, manifest themselves after a few minutes' action of the acid bath, it must be again thoroughly washed and returned to the alkaline bath. The finishing process consists in immersion in boiling water, and drying by the action of hot mahogany sawdust.

Cast-iron work is prepared for coating in the same manner as wrought-iron work, but requires more thorough cleansing than wrought-iron work does; this is especially the case with architectural mouldings and other pieces with much detail of design. It frequently happens that one portion of a casting will not coat with copper; this unfortunate tendency is due to the fact that even the best castings occasionally contain some portions that are not truly metallic, but are more like a compact cinder than anything else. A successful way of treating such castings is to wind a copper wire in wide helices round the offending part, taking care that the wire has an efficient connection with the negative pole of the electric arrangement; this wire is removed as soon as the deposit is seen to proceed with equality over the whole casting. The mahogany sawdust used in the finishing process must be carefully removed by a stiff brush while the work is still hot.

In this manner statuettes, railings, trellis work, bedsteads, stoves, and other ordinary iron castings, are made to receive an enduring coating of copper.

If the underneath metal is zinc, it is cleaned in the same manner as iron for the reception of the copper coating.

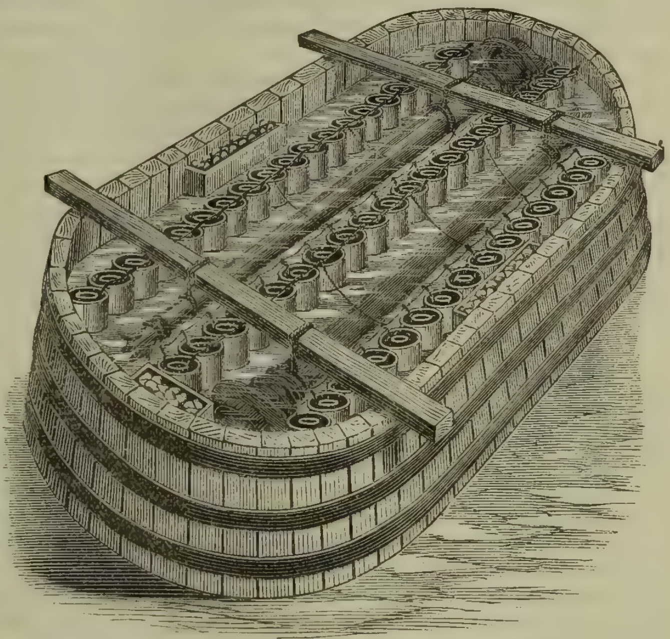
The same method of preparation is to be used in the case of electro-brassing as in electro-coppering; also, in most cases, the same plan of finishing the article. Wrought-iron work may, for the most part, be cleaned and at once immersed in the brassing bath; the same is true of steel articles. For the most perfect deposit, however, it is best to electro-brass upon a coating of copper. The previous coating of copper is absolutely necessary in electro-brassing cast iron. Zinc may be coated at once with brass, without being previously coated with copper.

Bronze deposits require the same preparation and after treatment as brass coating.

Copper, brass, and bronze deposits, of sufficient thickness, may be finished by means of brass finishing pickle.

One of the most remarkable exceptions to a general rule occurs in an invention which has been applied to the ornamentation of much of the iron work in the city of Paris. This consists in first covering the statue, lamp-post, or other similar article with an impervious and non-conducting varnish, coating this varnish in a perfect manner with powdered graphite, and immersing the prepared article in the ordinary sulphate of copper solution.* Fig. 23 shows the method employed, the articles being supported in a wooden vat from cross beams, and the electric power being supplied by a large number of cylindrical porous cells containing the positive fluid and zinc rods. The conducting wires are connected across to the various parts of the article under treatment. This plan affords a ready means of supplying the electric current at the place and in the degree in which it is wanted. Crystals of sulphate of copper are placed in perforated boxes at the upper part of the vat to replenish the solution. One of the

Fig. 23.



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* See Specification of Patent, No. 826, filed by Charles Francois Leopold Oudry, and dated March 25, 1857; also Specification of Patent, No. 2410, filed by John Henry Johnson (a communication from Charles Francois Leopold Oudry), and dated August 30, 1862.

varnishes (for instance), contains copal, resin, sulphur, walnut oil, benzole, and minium. To repair any defects in the coating, a "solder" may be used which contains galvanic copper, wax, copal, and resin.

Fig. 23 also serves to illustrate how any iron work which has already received a coating in the bath containing cyanide of copper, may have that coating thickened in a bath containing an acid solution of sulphate of copper.

Electro-nickeling.—Two inventions relate in part to the preparation of articles to be coated with nickel. In the first,[*] a mixture of quick-lime in powder and rouge is used to rub every part of the article until all grease is removed. The articles are then placed in the nickel bath in a dry state; or, a solution of sulphate of iron mixed with dry lime may be used. In the second invention, the same method of preparation is adopted; the depositing solution consists of the double tartrate of nickel and an alkali.

Electro-nickeling is now extensively applied to iron and steel articles of the finer sort, and to metallic house furniture. The cleaning of the original articles is the same as for plating and coppering. In this manner gun barrels, swords, scabbards, and other military equipments are often ornamented and protected from corrosion.

Electro-deposition of Iron.—This coating is successfully applied to covering engraved copper plates, so as to enable them to yield a large number of impressions.[†] JOUBERT's solution (the chloride) is to our knowledge used for this purpose; by this means a very thin and uniform coating is given to the plate, so thin that the design is practically unaltered, and the plate for the time becomes a steel plate. The metal should be quite bright. Immediately on taking the copper plate from the bath, it is washed by means of jets of water, dried and washed with spirits of turpentine; it is then ready for printing from. Before the coating of iron is entirely worn away, it may be removed by acids, and the printing surface may then be re-covered with an iron coating as often as may be required. Dilute nitric acid is used to remove iron from copper.

The chief purpose of electro-coating metals is to give them a perfectly adherent metallic surface that will be less destructible than the underneath metal, and renders the article more beautiful. This department of electro-metallurgy enables a comparatively inexpensive metal to be used for works of art, and a material to be selected that is easier to work than the deposited metal.

APPLICATIONS OF ELECTROTYPY.—The distinction between the art of electro-coating and that of electrotypy is, that in the former case the deposited metal forms an intrinsic portion of the metal or article operated upon, whereas in the latter case the deposit is disunited from the substance receiving it, and forms a separate and distinct work of art. A still more general definition may be given by saying that the first is covering or encasing one metal with another, and the second is producing a perfect copy of a surface, which may be metallic and conductible, or non-metallic and non-conductible. In the case of a cast from the original not being conductible, its surface must be made so by special processes.

Copying Coins.—If the coin be not a very precious one, and will bear immersion in the sulphate of copper solution, an electrotype may be taken from one face of the coin to form a mould, and the electrotype taken from that mould will be a fac-simile of the original face of the coin that is subjected to the operation. A fine copper wire is put round the edge of the coin and fastened by twisting, a sufficient length of wire being left out for electrical connection. The back part of the coin, where no deposit is required, is embedded in gutta percha, and the cleansed front part is slightly greased with olive oil. The greasing is best accomplished by means of a camel hair pencil, and subsequent wiping off with a silk fabric; this operation is necessary to prevent the adhesion of the deposited metal to the face of the coin. The free end of the wire is then connected to the zinc plate of a single-cell apparatus, and the mounted coin is placed in its outer vessel, so that the uncovered face of the coin is parallel to the flat surface of the zinc plate. Provided that the relative sizes of the zinc plate and of the coin be adjusted according to the principles that have been laid down, a beautiful pink deposit of copper immediately commences, and the thickness of the deposit depends upon the time that the apparatus is kept in action. Twenty-four hours should give a deposit of about ·015 inch in thickness. The wire may then be untwisted from the edge of the coin, and the deposit detached from its mould; the latter operation may require the skilful use of the edge of a knife.

The mould may be similarly treated any number of times, so as to produce any number of duplicates of the face of the coin; the other face may be similarly treated for mould and duplicates, and the two faces (obverse and reverse) of each pair of duplicates may be trimmed, soldered together, and electro-silvered or electro-gilt, so as to present exact copies of the original coin.

By the above example it will be seen that the requirements of work in electrotypy are:—

1. The cleansed and prepared article.
2. The mould, metallic or non-metallic.
3. The preparation or metallization of the mould.
4. The electro-deposition of the metal.
5. The mounting or finishing of the cast.

The article must be prepared and mounted according to the process for obtaining the mould. If there be a number of similar casts to be taken it may be worth while to have an electro-deposited mould, as in the case of the coin above cited. In many cases, however, this is inconvenient, and almost impossible. In the instance of a valuable medal or coin it might not be well to risk the action of the solution upon it, or the chance of the deposited metal sticking to it. A plaster cast, or a mould by pressure in gutta percha, had better be taken. If a mould be taken in a non-conducting substance, it requires metallizing; this process will be set forth in its place. To take the mould of a bust all in one piece, elastic moulding composition is required; this composition is composed of 4 parts of Russian glue and 1 part of treacle; the glue is broken into small pieces and soaked for one or two hours, or until it is quite soft, in sufficient cold water to cover it; the superfluous water is then thrown away, and the glue, together with the treacle, is heated in a common glue pot to nearly boiling and stirred. To take a mould of a coin it is useful to surround its edge with a strip of thin brass, in order to confine the plaster or gutta percha which is used for the mould. If the mould be taken in plaster it must be made non-porous by being dried and allowed to remain in melted wax until it is quite saturated therewith. Moulds may also be taken in fusible metal, or in a composition containing wax and stearine.

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[*] See Specification of Patent, No. 1492, filed by Henry John Brook, Edward Goodrick Draper, and John Unwin, and dated April 29, 1874.

[†] See Specification of Patent, No. 667, filed by Edmond Auguste Jacquin (a communication from Henry Garnier), and dated March 29, 1858.

The operation of metallizing may be performed by brushing with black lead, by means of a chemical coating of gold or silver, or by immersion in a solution of phosphorus in bisulphide of carbon, and then into a solution of silver or gold. Elastic moulds may be made to contain the required amount of phosphorus to reduce the metal.

The metal may be electro-deposited either by the single-cell process or by a separate source of electricity; for some articles, however, the single-cell process has many advantages. The electro-cast, when obtained, may be backed by solder, or otherwise mounted, and then bronzed on the face by the application thereto with a brush of a platinum solution mixed with crocus, and sulphide of ammonium and colouring material.

Besides the application of electrotyping to the reduplication of works of art, it has been extensively applied to copying natural objects, engraved copper plates, and to stereotyping in copper. Photo-electrotypy has also been practised by Woodbury and others; one of the plans is to take an electrotype from the reverse of a bichromated gelatine mould. Electro-casts of leather are used to ornament the binding of books, and to furnish ornamental surfaces for various purposes.

Reducing Metals from their ores by Electro-deposition.—Much that has been enunciated in respect to depositing solutions, especially those relating to the metals that are comparatively rare, may be made available for the reduction of metals from their ores or other chemical combinations. Sir Humphrey Davy, in 1807,[*] by his discovery of the metals of the alkalies, started this practical application of the new power. Dr. Golding Bird, in 1837,[†] produced potassium, sodium, and ammonium as amalgams, and obtained silicium in a metallic state; for this purpose a current of low tension was employed to decompose the fluoride of silicium and the chlorides of the alkaline metals. Andrew Crosse[‡] reduced copper from a sulphuric acid solution of the calcined ore; a positive pole of platinum wire-work was placed in contact with the ore at the bottom of the trough, and a "basin of wood" lined with sheet copper was connected by its lining with the negative pole of the battery, the liquid being heated. William Petrie[§] put forward a method of precipitating silver, copper, &c., from the solutions obtained in refining gold and silver; the silver he precipitated by metallic copper, and the cupreous solution was made to yield its copper by electrolysis. Charles Griffin[‖] electro-deposited copper "from its solutions formed by nature, or in the various processes of purifying cupreous ores by washing them with water."

James Balleny Elkington[¶] more recently brought out a plan (still in use) for the manufacture of copper from copper ore. The ore is treated in the ordinary manner by heat till it is brought to a regulus or blister metal, previous to the ordinary refining process by heat. Then instead of refining by heat, the products are refined by electric currents, by employing the said products as positive plates in a solution by which the copper in these plates will be dissolved and deposited as pure copper on the surfaces of the negative poles employed, whilst the other metals previously combined with the copper in the unrefined plates at the positive poles, will be precipitated at the bottom of the trough. The blister copper is cast (as it comes from the furnace) into plates which are arranged in rows as positive plates in a depositing trough. Between each row the negative plates are arranged; these consist of pure thin rolled copper. A series of, say, twenty-five troughs are thus made up, the negative plates of one trough being in connection with the positive plates of the next, and so on. The solution in the troughs is nearly saturated sulphate of copper. For 16 square feet (both sides) of negative plates in each trough, the magneto-electric machine should be such as would be used in electro-plating with a silver plate 20 square feet of surface, or a machine having fifty permanent magnets, each weighing 28 lbs.

From what has been already described, it will be apparent that the application of electricity to the reduction of metals from their ores has a future which is highly promising for the production of pure metal.

Electric Etching.—This is an application of electric power to the engraver's art. By properly preparing a copper or other plate for etching, and placing it as an anode in a solution which will only act upon it during the passage of the electric current, the plate becomes engraved with a great amount of certainty and success.

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[*] See Philosophical Transactions, Bakerian Lecture, 1807.

[†] See Philosophical Transactions, 1837.

[‡] See Specification of Patent, No. 14,280 (old law), filed by Andrew Crosse, and dated August 26, 1852.

[§] See Specification of Patent, No. 14,346 (old law), filed by William Petrie, and dated November 13, 1852.

[‖] See Provisional Specification, No. 1035, filed by Charles Griffin, and dated December 11, 1852.

[¶] See Specification of Patent, No. 2838, filed by James Balleny Elkington, and dated November 3, 1865.

The peculiarities of this method of working will be best shown by the following points in the history of the subject:—Messrs. Spencer and Wilson's plan [*] consists in placing the prepared surface to be etched in connection with the positive pole of a voltaic arrangement and in a vessel containing a suitable solution, opposite to a conducting surface which communicates with the negative pole of the battery. During the process the engraved plate may be withdrawn and examined, and if necessary replaced. When some of the lines are required to be fainter than others, such parts of the design may be stopped out. Grove, in 1841, read a paper at a meeting of the London Electrical Society, in which he proposed to etch daguerreotypes by the electric current. The solution used consists of moderately dilute hydrochloric acid. S. B. Smith uses a solution of gutta percha as a stopping out varnish for electro-etching. [†]

The following is Theobald Denny's process [‡] for engraving:—A plate of polished steel is covered with a solution of india-rubber, and is blackened by passing over it an ignited wick. Heat is then applied to the plate till it becomes a bluish-white colour; the drawing is etched upon this surface, which is then waxed with a slight film of virgin wax. The plate is then plunged for two seconds into a cyanide of potassium and copper bath that contains tannin, and is thereby electro-coppered; it is then cleaned with alcohol, electro-silvered, cleaned, heated, covered with a solution of colophony, spread over with wax, and cleaned again with cotton wadding. The exposed parts of the steel plate are then bitten out, by making the plate (treated as above) the anode in a concentrated solution of sulphate of iron and chloride of ammonium. The silver and copper coatings are then removed, rubbed down, and the steel plate is exposed for a minute or two to the dissolving action of the battery in the bath of sulphate of iron and chloride of ammonium, in order to remove the polish and lustre of the engraved surface, so as to allow the printing ink to lay well. [§] Devincenzi's method of obtaining surfaces for printing from is as follows:—Impressions are obtained with some greasy matters on a metallic plate, and a varnish is applied to them that is able to resist electro-chemical action. The metallic surfaces thus prepared are engraved by electro-chemical action. For steel or zinc engravings a solution of sulphate of copper and a single cell is used. To obtain different degrees of depth in an engraving, the portions that are sufficiently engraved are covered with a varnish, and the surface is again submitted to electrical action. Modifications of this process, involving electro-deposition, are described by the patentee. Fontainemoreau's plan [||] is to draw a design in lithographic ink on a roughened zinc plate. A resinous powder is then dusted over the plate, and the superfluous powder removed, so that the drawing alone is coated with the above mixture. The powder, which is composed of resin, Burgundy pitch, and asphalte, is heated and thus converted into a stopping out varnish. The plate is then placed in a weak solution of sulphate of zinc and etched by electrical means. Bellford has a somewhat similar plan [¶] of engraving, in which the operations of inking and electro-etching are alternately carried out. This invention may be applied to making calico-printing blocks. Messrs. Ernst and Lorberg transfer copies to a metal plate by means of transfer ink. The plate is then protected at the back by varnish, and electro-etched. By this process the design is left in relief on the surface of the plate. In another invention Devincenzi [**] produces a grain on a metallic plate, draws on it with varnish, and electro-etches it. Nègre electro-deposits gold upon portions of the surface of another metal, and electro-etches those parts of the design that are not electro-gilt. The solution used is a neutral solution of a soluble salt of the underneath metal.

Theory of Electro-metallurgy.—The action of the various instruments used to obtain the electric currents used in electro-metallurgy having been explained, it is necessary in this place to notice some changes that have taken place in the nomenclature of electrical forces; these changes have mainly been brought about by the necessity for the precise definition of numerical units for telegraphic purposes. The old terms quantity and intensity were not used to define any quality of electricity to which numerical values could be assigned; they were conventional words that were principally used to define the kind of electric current to be used for a given class of electro-metallurgical work. Smee defines intensity as the power which the voltaic fluid possesses of overcoming obstacles, and quantity as being proportionate to the amount of action on the zinc plate of a battery. These notions, as mentally received by some electro-metallurgists, are founded upon the idea that electricity is analogous in its behaviour to a bullet shot out of a gun, the weight of the bullet representing the quantity, and the velocity the intensity, of a certain amount of electricity passing in a given time. Electricity cannot, however, be said to have speed, for the current is a constantly flowing force, and not a bit of a force, and in a given circuit it grows gradually from a minimum to a maximum. The introduction of a function especially belonging to electric force, and new to science, called resistance, by Dr. G. S. Ohm, in 1827, has been the means of reducing the data that occur in electrical science to exact numerical values. The following definitions will make this quite clear:—

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[*] See Specification of Patent, No. 8656 (old law), filed by Thomas Spencer and John Wilson, and dated October 7, 1840.

[†] See Specification of Patent, No. 12.654 (old law), filed by Stanhope Baynes Smith, and dated June 7, 1849.

[‡] See Specification of Patent, No. 478, filed by Theobald Denny, and dated February 28, 1854.

[§] See Specification of Patent, No. 868, filed by Giuseppe Devincenzi, and dated April 13, 1854.

[||] See Provisional Specification, No. 1582, filed by Peter Armand de Fontainemoreau (a communication), and dated July 18, 1854.

[¶] See Specification of Patent, No. 1679, filed by Auguste Edouard Loradoux Bellford (a communication), and dated July 29, 1854.

[**] See Specification of Patent, No. 526, filed by Giuseppe Devincenzi, and dated February 23, 1857.

Electro-motive force, the force which causes or tends to cause a transfer of electricity. The electromotive force of a galvanic cell depends upon the materials of which it is constructed. The electromotive force is proportional to the number of cells joined in series.

Strength of current, the quantity of electricity which flows through a given section of the electric circuit in a given time. It may be measured by the amount of electrolysis in a given time.

Resistance, the impediment to the passage of a current.

According to Ohm's law:—When a current is produced in a conductor by an electro-motive force, the ratio of the electro-motive force to the current is independent of the strength of the current, and is called the resistance of the conductor.

If C = the current, E = the electro-motive force, and R = the resistance of the conductor, then $C = \frac{E}{R}$, or $R = \frac{E}{C}$, or $E = CR$.

This definition of resistance would not be justified if we did not always obtain one and the same value for R in any one conductor, whatever electromotive force may be employed to force a current through it. The electrical resistance of a conductor is not analogous to mechanical resistance, such as the friction which water experiences in passing through a pipe, for this frictional resistance is not constant when different quantities of water are being forced through the pipe; whereas the magnitude called electrical resistance is quite constant, whatever quantity of electricity be forced through the conductor. This fact leads to much greater simplicity in the calculations of the distribution of electrical currents than in calculations of the flow of water.

It therefore follows that the unit of resistance may be defined by a wire of a given quality, length, and weight. A committee of the British Association for the Advancement of Science has determined this unit to be a wire of gold-silver alloy 0·5995 mètres long, 1 mètre of which weighs 1 grm.* This unit is called an ohm. An ohm may also be defined as a resistance of 485 mètres of pure copper wire, 1 millimètre diameter, at 0° C.

By means of a series of resistance coils made to correspond to definite units of resistance, and stops or "shunts" adapted thereto, the resistance of a metallic circuit, of a depositing solution, or the internal resistance of the battery itself, may be determined with the greatest exactness. Few batteries have less resistance than one ohm; a Grove's cell may be constructed, however, to have only one-fourth of an ohm resistance.

The laws of electro-chemical action are:—

1. That the consumption of zinc in each battery cell, arranged in series, is the same in every cell.

2. That the same quantity of electricity will decompose equivalent quantities of each substance electrolyzed. The quantity of a substance which is electrolyzed by one unit of electricity is called the electro-chemical equivalent of that substance.

3. That acids and similar substances go to the anode of a depositing or decomposition cell.

4. That alkalies, metals, and similar substances go to the cathode.

The following are examples of electrolytic decompositions which require the same quantity of electricity to effect them:—

Substance Decomposed.	Mass Decomposed.	Masses of Products.
Water	18	2 hydrogen, 16 oxygen.
Hydrochloric acid,	73	2 hydrogen, 71 chlorine.
Potassium chloride,	149	78 potassium, 71 chlorine
Sodium chloride,	117	46 sodium, 71 chlorine.
Silver chloride,	287	216 silver, 71 chlorine.
Potassium iodide,	332	78 potassium, 254 iodine.
Potassium bromide,	238	78 potassium, 160 bromine.
Calcium chloride	111	40 calcium, 71 chlorine.
Zinc chloride,	136	65 zinc, 71 chlorine.
Ferrous chloride,	127	56 iron, 71 chlorine.
Ferric chloride,	108⅓	37⅓ iron, 71 chlorine.
Cuprous chloride,	198	127 copper, 71 chlorine.
Cupric chloride,	134½	63½ copper, 71 chlorine.
Mercuric chloride	271	200 mercury, 71 chlorine.
Potassium sulphate,	174	78 potassium.
Zinc sulphate,	163	65 zinc.
Lead nitrate,	331	207 lead.
Silver nitrate	340	216 silver.
Stannous chloride,	189	118 tin, 71 chlorine.
Stannic chloride,	130	59 tin, 71 chlorine.

ENAMELS.—*Emaux*, French; *Schmelzglas*, German; *Encausti*, Latin.—Enamels are varieties of glass, with a varying degree of fusibility and opacity. They are coloured by different metallic oxides, to which certain persistent fusible salts are added, such as the borates, fluorides, phosphates, &c.

The ancients carried the art of enamelling to a very high degree of perfection, and beautiful specimens of their ingenuity are occasionally found, of which neither the composition nor the mode of applying it is known. Then, as at present, each artizan made a mystery of the means that succeeded best with him, and thus a great number of curious processes have been buried with their originator. Another cause contributes powerfully to the declension of this art. Among the vast numbers of prescriptions which have been given or published for the formation of enamels, there are several in which substances are mentioned that can no longer be procured, either owing to a change of denomination, or because they cannot now be found in commerce, or else because they are not of the same nature as of old. Hence, in numerous instances, it is found impossible to obtain satisfactory results.

A singular circumstance may be here noticed, which is, that a vitreous mass containing copper, when removed from the melting pot, sometimes only exhibits a faint greenish hue, but whilst in this state a simple exposure to a gentle heat brings forth a brilliant red.

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* See British Association Reports for 1863 and 1864.

Glass containing gold exhibits the same singular change of tint under similar circumstances.

SPLITTBERGER made specimens of glass many years ago which contained chloride of gold. They were white, but when heated in the flame of a spirit lamp they assumed a deep-red tinge. If, again, this red glass was subjected to the heat of a blowpipe, it lost nearly all its colour. These metamorphoses have been vaguely attributed to different degrees of oxidation in the metal; but if this be the case, it is strange that mere exposure to a slight temperature can effect a chemical variation in the interior of a solid mass of glass, which has already undergone a heat far more intense. BECKMANN found that metallic gold gives the red colour as well as its oxide. It has for many years been known that silver imparts a colour to glass while in the metallic state, and everything leads one to the supposition that the case is the same with gold.

The material employed of old to tinge glass red was the suboxide of copper; but on the discontinuance of the art of glass-painting the dependent manufacture of ruby glass of course ceased, and the process became so entirely extinct that the idea generally prevailed that the colour in question was derived from gold. In 1793 the French government actually collected a quantity of ancient glass with the view of extracting the gold by which it was supposed to be tinged. It is, however, perfectly true that glass was formerly coloured red by gold; FARADAY found that such glass, whilst ruby by transmitted light, was more or less opalescent by reflected light, the colour being due to the diffusion of extremely fine particles of metallic gold through the mass of the glass.*

The Venetians possess the best processes for making enamels, and supply the rest of the world.

Enamels are distinguished into transparent and opaque; in the former, all the components have been fused and run into crystal glass; whilst, in the latter, some of them have better resisted the action of heat, so that their particles retain sufficient aggregation to prevent the transmission of light. This effect is produced particularly by the stannous oxide (monoxide of tin), as will be perceived when treating of white enamel. The frits of enamels that are to be applied to metallic surfaces require greater fusibility, and should therefore contain more flux; and the sand used for these should be calcined beforehand with one-fourth its weight of chloride of sodium; sometimes, indeed, metallic fluxes are added, as minium or litharge. For some metallic colours the oxides of lead are very injurious; in such a case other fluxes must be used.

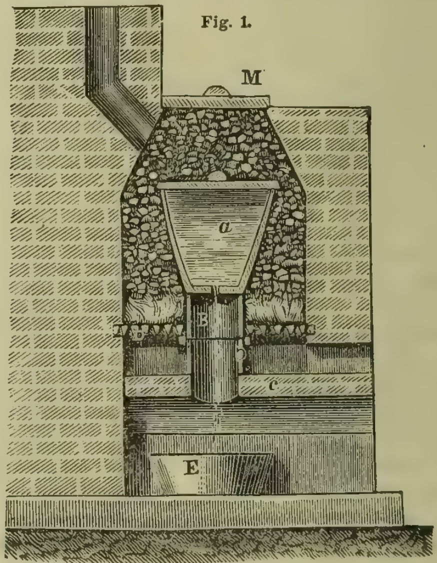
The following mixtures have been found serviceable for purples, blues, and some other delicate colours:—

Three parts of silicious sand, one of chalk, and three of calcined borax; or three of glass—of broken crystal vessels—one of calcined borax, one-fourth of a part of nitrate of soda, one part of well-washed antimoniate of potassa. These compositions afford a very white enamel, which accords perfectly well with blue.

The composition of this primary matter may be greatly varied; but one should never lose sight of the essential quality of a good enamel, which is, to acquire, at a moderate heat, sufficient fluidity to take a shining surface without running too thin. It is not perfect fusion that is wanted, but a pasty state, of such a degree as may give it, after cooling, the aspect of having suffered complete liquefaction.

The mode of melting the materials for the groundwork is shown in Fig. 1. The oven is round, and is fed with coal or coke; it has an opening at the top covered with the lid, M; through this opening the materials, after being thoroughly mixed, are passed into the crucible, *a*. The crucible rests on the cylindrical tube, B. The brickwork, C, forms an air channel to keep up the combustion of the coals upon the grate, D. The fire is lit at the bottom, as the heat increases the ingredients are fused, and flow down through a hole in the bottom of the crucible into a vessel of water, E. The granulation thus produced renders pulverization more easy.

Fig. 1.



The enamel furnace for bijouterie is represented in Fig. 2. After the articles have been covered with the mixtures to form the glaze, they are inserted in the muffle, A, a thin clay vessel heated from without by the fire-place, B, of the furnace. The mouth of the muffle exactly fits the aperture, C. The pierced plate of clay, D D, answers the purpose of a grate, and is supplied with air by three apertures, E E, of the ash-pit, F. A ledge, G, is erected for convenience before the working-hole, C, and is supported by the cheeks, H H. The aperture, K, is for the purpose of stirring the fire, and can be closed like any one of the others by a clay door.

Before the work is begun the furnace must be made red-hot; the pieces are then inserted, and the aperture, C, is closed in such a manner as to leave a small crack, through which the fusion can be watched. The success of the enamelling process depends upon a proper mean being maintained between that temperature which would cause the enamel to flow, and that at which it only imperfectly softens and its surface remains rough. The most common defect in the appearance of enamelled articles is caused, however, by air bubbles which have not found an opportunity of fully effecting their escape. These either occasion a protuberance, or when they have burst, a concavity, which frequently render it necessary, subsequently, to give a finish to the piece.

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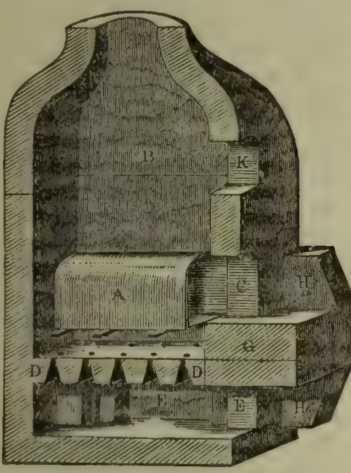
* Royal Institution Proceedings, vol. iv. p. 311.

Fig. 2.



Dead-white Enamel.—Great nicety is necessary in the choice of the materials, as it must be perfectly free from every kind of colour; hence the frit employed in this case should be itself composed of perfectly pure ingredients. But a frit should not be rejected hastily because it may be somewhat discoloured, since this may depend upon two causes—either on some metallic oxides, or on carbonaceous particles proceeding from vegetable or animal substances. Now, the latter impurities may be easily removed by means of small quantities of binoxide of manganese, which has the property of readily parting with a portion of its oxygen, and of thus facilitating the combustion (that is to say, the destruction) of the colouring carbonaceous matter. Manganese itself possesses a tinctorial power on glass, but only in a very high state of oxidation, and when reduced to the lower state, as is done by incombustible matters, it no longer tinges enamel combinations. Hence the proportion of manganese should never exceed what is requisite; for any surplus would cause colour. Sometimes, indeed, it becomes necessary to give a little manganese tinge in order to obtain a more agreeable shade of white, as a little azure blue is added to linens to brighten or counteract the dulness of their yellow tint.

A white enamel may be conveniently prepared with a "calcine" composed of 2 parts of tin and 1 of lead, calcined together; of this combined oxide 1 part is melted with 2 parts of fine crystal glass and a very little manganese, all previously ground together. When the fusion is complete the vitreous matter is to be poured or suffered to run into clear water, as in Fig. 1, and the frit is then dried and remelted. The pouring into water and fusion are sometimes repeated four times, in order to secure a very uniform combination. The crucible must be carefully screened from smoke or flame. The smallest portions of oxide of iron or copper admitted into this enamel will destroy its value.

Some enamellers recommend the use of washed potassium antimoniate (from metallic antimony and nitre fused together) for white enamel; but this product cannot be added to any preparation of lead or other metallic oxides, since it would tend rather to tarnish the colour than to clean it up, and it can be used, therefore, only with ordinary glass or with saline fluxes. For 3 parts of white glass, without lead, 1 part of washed antimoniate of potash is to be taken; the substances are well ground together, and fused in the common way.

White enamel, either for earthenware or for applying on metals, may also be composed as follows: A mixture of lead and tin is calcined, which may vary in the following proportions, namely, for 100 parts of lead, 15, 20, 30, and even 40 of tin. The mixture of these two metals calcines readily with the contact of air. As soon as this alloy is heated to the point of incipient redness it burns like charcoal, and calcines very fast. The best quantities are those which, for 100 of lead, contain 20 to 25 of tin. In proportion as the calcination is effected the heated part is withdrawn, and the rest is continued to be oxidized till the whole becomes pulverulent. As some small grains always escape, the oxide obtained is passed a second time into the fire in order to heat it completely, which is known to be the case when it no longer sparkles; that is to say, when one no longer observes parts which burn like coals, and the whole appears of one uniform colour.

When the proportion of tin exceeds 25 or 30, a stronger fire is required. However, by varying the power of the fire one may ascertain that which suits best for the bodies operated upon. 100 parts of the above mixture are usually taken, and the same of sand: 25 to 30 lbs. of chloride of sodium are now to be added, the whole well rubbed together, and the mixture put to melt on the furnace in which the ware is baked. This article is usually placed in sand, or lime slaked in the air, or on ashes.

The lower part of the mass is pretty generally not well melted. Nevertheless this does not prevent it, when crushed to powder and afterwards put in the goods, becoming very white in baking in the furnace. When withdrawn from under the furnace it is not white; it is often even rather black: usually it is marbled a black, grey, and white.

This method of procedure is that which is practised in the potteries. In the compositions intended for such works the proportion of 25 of tin to 100 of lead is never exceeded; even for common earthenware potters are satisfied with 15 of tin to 100 of lead.

It is obvious that, if it be wished to obtain a whiter and more fusible enamel, the quantity of sand must be diminished, while that of the chloride of sodium must be increased; as the whiteness and opacity depend on the quantity of tin, 25 or 30 of the "calcine" may be taken to 100 parts. For example, 100 of the mixture, 60 of the sand, and 25 of metallic chloride, give a very fusible composition.

Further manipulations are necessary to obtain enamels fit for being laid on metals.

In that case crude sand is not used; but the raw sand is calcined with one-fourth of its weight of chloride of sodium in a crucible, on the small scale, over a strong fire, or on the large in a furnace; further, if a very fusible enamel is desired, it is mixed with minium or with lead calcined in this first operation, nearly in the same proportion as with salt, that is to say, one-fourth; a white mass is then obtained, half-melted and porous, which is pulverized, and is used in the composition of the enamel instead of the sand. This substance may even be diminished to 50 per cent. if a very fusible enamel is desired. It depends also on the kind of "calcine" employed, for that which contains most tin is least soluble.

When fluxes for the colours are required, the same compositions above mentioned are used, except that little or no tin is put in the lead. In the latter case minium is usually taken. This flux is good for certain colours, but not for all. It is found that fluxes into which oxides of lead enter tarnish; in that case other fluxes are formed without oxide of lead; nitrate of soda and borax are usually employed to make these glasses; no calcine of tin is used. The following results were found by CLOUET: 3 parts of silicious sand, 1 of chalk, 3 of calcined borax, give a substance suitable to serve as a flux for purples, blues, and other delicate colours; 3 of white glass, 1 of calcined borax, one-fourth part of nitrate of soda, yield a very white enamel, which may serve also as a flux for purple, and especially for blue.

Sixty parts or less of enamel sand, 30 of alum, 35 of chloride of sodium, and 100 of minium or other oxide of lead, yield a white enamel when the fluxes do not predominate too much; and a gelatinous glass when the latter are in large quantity. The glass is good for red, and the enamel does for all clays or earths which can stand a strong fire.

It is very important to observe that the sand used for enamels must contain talc as well as silica. It requires nearly one part of talc to three of silicious sand to make enamels, colour fluxes, &c. The choice of the sand is essential for success in enamelling. This sand can be procured in places where earthenware is made. It is easily known; independently of the silica which constitutes the greater part of it, talcy particles are found in it in great quantity, and, to be good, it must contain about one-fourth; when it does not contain enough, the enamel which it produces is more difficult to melt, and does not become smooth; it remains grainy, and makes what is called "egg-shell."

It is essential that the lead and tin destined to make the oxide for producing the white enamel be melted and mixed together before being calcined; and if it be desired that the enamel have all its whiteness immediately, this calcination should be very complete.

The principal characteristic of a good enamel, and which renders it fitted to be laid on baked clays, earths, or metals, is its facility in glazing with a moderate fire—a cherry-red heat, or a little more or less, according to the nature of the enamel—without entering into complete fusion. These are the qualities possessed by enamels which are applied on pottery or earthenware articles. They do not enter into complete fusion, otherwise they fail; they take only a pasty state—indeed, a very firm paste; and yet, when they are baked, they appear as if they had been completely melted.

There are two modes of painting on enamels—on the crude, or on the baked. Both of these methods may be employed on the same object. Solid colours may be laid on which can stand the fire necessary for baking in melting the crude enamel, and the article afterwards finished with delicate colours. The hues which are laid on the crude enamel do not require a flux; there is one, however, to which silica must be added, namely, the calcine of copper, which gives a very fine green; but when it is wished to employ it on the crude enamel, it must be mixed with about 2 parts by weight of silica, and the heat raised till the mixture enters into combination. The mass obtained is afterwards pulverized for use.

It is also essential, in order to have the enamel very white, to make sure of the purity of the lead and tin. If these metals contain copper or antimony, as pretty often happens, the enamel will not be fine. Iron is less hurtful.

COLOURED ENAMELS.—All the colours are produced with metallic oxides. These are more or less fixed in the fire, according as they hold more or less strongly to their oxygen; thus, all the metals which easily lose this element cannot stand a great degree of heat, and cannot be employed on the crude enamel.

Purple.—This colour is oxide of gold, which can be prepared in different manners, either by precipitating a solution of gold much diluted with water with tin, or by the chloride of tin. As little as possible of the stannic solution should be used; it is added gradually till the purplish colour appears, then no more is added, and the colour is left to deposit, and afterwards poured into a glass vessel to dry it slowly. The different solutions of gold, in whatever manner precipitated, provided the gold is thrown down in the state of oxide, give always a purple hue—so much the finer the purer the oxide; however, neither the copper nor the silver, which usually exist alloyed with the gold, spoil this tint very perceptibly. Iron changes it; but the precipitate of gold which gives the finest purple is, without contradiction, fulminating gold, which loses this property when it is mixed with fluxes.

The purple is a powerful colour; it can bear much flux, and in small quantity imparts its colour to much matter.

It appears that the saline fluxes agree better with it than those into which the metallic calcines enter; thus it will be necessary to give it those which are made with silica, carbonate of lime, and borax; or white glass, borax, a little white oxide of antimony.

and nitrate of soda. Purple can bear, or carry, from 4 to 20 parts, and even more, of flux, according to the shade desired. Painters on enamels usually employ for purple a flux which they name "brilliant white;" this is a semi-opaque white enamel, which is put on tubes, and afterwards blown into bulbs at the enameller's lamp. The bulbs are afterwards broken, so that this flux is found in commerce in small scales, which have the appearance of *débris* of minute hollow spheres. Painters in enamel mix this flux with a little nitrate of soda and borax. Purple does not stand a strong fire.

Yellow.—To obtain these hues metallic oxides are employed, the complete vitrification of which is prevented by mixing them with other substances, such as refractory earths or metallic oxides difficult of fusion.

The metallic mixtures which constitute the base of the yellows are usually those of lead, minium, white-lead, or litharge; an alkaline antimoniate is also used. The following are the different compositions practised:—1 part of white oxide of antimony, 1 of carbonate of lead, or 2 or 3 parts (these proportions are very variable), 1 part of alum, and 1 part of ammoniacal salt. These substances are pulverized and mixed well together; and are then put into a vessel on a fire sufficient to sublime and decompose the ammoniacal salt; and the operation is finished when the matter has taken a fine yellow colour. The oxide of lead mixed, in small quantity, either with silica or alumina, also with pure oxides of tin, very white, gives likewise yellows; 1 part of oxide of lead is put to 2, 3, or 4 of the other above-mentioned substances. Ferric oxide may also be taken for these different yellow compositions. Different shades of yellow are then obtained, and these may be varied to any desired extent.

The yellows require a little flux; 1 part or 2 usually suffice. The saline fluxes do not agree with them, especially those into which nitrate of soda enters.

They must be used with fluxes composed of enamel sand, oxide of lead, and borax, suppressing the chloride of sodium. A yellow may also be drawn directly from oxide of silver, the best way of using which is to employ it pure; the enameller then tints, not paints with it; it is sufficient to put a slight film of it in the place to be coloured, and heat the article slightly to give it the hue; the fire must not be too strong; the proper degree will be easily found. When the article has been heated to the point necessary, it is withdrawn from the fire, and the coating of oxide of silver which has been put on, and which should be found reduced to a regulus, is taken off, when the place which it occupies is seen to be tinged a very fine yellow, and having no thickness. It is chiefly on transparent glasses that this process succeeds best; very fine silver filings produce also this effect. The sulphate of silver succeeds very well, pounded with a little water to lay it on evenly. As the pellicle of silver which covers the colour has to be removed, it is requisite to avoid fixing the film with fluxes; and it ought therefore to be applied after the fusion of the rest, for, as it is very fusible and easily changed, it would deteriorate with the other colours; and as the coating of silver which is reduced must be taken off, the fluxes would fix it, and it could not be removed. This annoyance does not take place with glass, for the silver-yellow is laid on the opposite sides from the other colours. The red calcine of iron, quite alone, when it enters into fusion with the glasses, gives a tint which appears black; if this be diffused over a sufficient quantity of glass, it becomes at last a transparent yellow. Thus the tint which is really given by the iron combined with the glasses is a yellow one; but which, being concentrated, becomes so deep that it appears black.

Although yellow may be obtained directly, the above compound yellows are preferred, because they are of surer and easier use than the hue which may be obtained directly from the silver.

Green Enamel.—A green colour may be produced by a mixture of yellow and blue, but this is seldom done, as it can be better obtained directly with oxide of copper, or oxide of chromium. The latter has the great advantage of resisting a strong heat.

Cupric oxide is blue in the state of hydrate, but blackish-brown when dry, and colours green all the vitreous combinations into which it enters. Oxide of copper requires, at most, one or two proportions of flux, either saline or metallic, to enter into complete fusion; but a much smaller dose is commonly taken, and a little oxide of iron is introduced. To 4 lbs. of frit, for instance, 2 ozs. of cupric oxide of copper and 48 grains of ferric oxide are used; and the ordinary measures are pursued for making a very homogeneous enamel.

The green produced by the oxide of chromium is much more solid; it is not affected by a powerful fire, but is not always of a fine shade. It generally inclines too much to the dead-leaf yellow; this depends, however, on the degree of oxidation of the chromium.

Red Enamel.—Suboxide of copper (cupreous oxide) affords a fine red colour when it can be fixed, a result difficult to obtain on account of its fugitive nature, slight variations of temperature enabling it to absorb more oxygen. The proper point of fusion must be seized for taking it from the fire whenever the desired hue is brought out; but when a high temperature has produced a greater degree of oxidation, this may be corrected by adding some combustible deoxidizing matter, as charcoal, tallow, tartar, &c.

The copper then returns to its lower state of oxidation, and the red colour which had vanished reappears. It is possible in this way, and by pushing the heat a little, to accomplish the complete reduction of a part of the oxide; and the particles of metallic copper thereby disseminated in a reddish ground give this enamel the aspect of the stone called *aventurin.* The easiest and most certain method of procuring suboxide of copper is to boil a solution of equal parts of sugar and sulphate, or acetate of copper, in four parts of water. The sugar takes possession of a portion of the oxygen of the cupreous oxide, and reduces it to the suboxide, when it may be precipitated in the form of a granular powder of a brilliant red. After about two hours of moderate ebullition, the liquid is set aside to settle; the precipitate decanted off, is washed and dried.

Pure red oxide, properly employed by itself, furnishes a hue which vies with the finest carmine, and by its means every tint may be obtained from red to orange, by adding a greater or smaller quantity of sesquioxide of iron.

The preparations of gold, and particularly the oxide and the purple of Cassius, are likewise employed with advantage to colour enamel red, and this composition resists a powerful fire tolerably well.

For some time back solutions of gold, silver, and platinum have been used with success instead of their oxides; and in this way a more intimate mixture may be procured, and, consequently, more homogeneous tints.

Blue Enamel.—This fine colour is almost always obtained from the oxide of cobalt or some of its combinations, and these produce it with such intensity that only a very little can be used, lest the shade should pass into black. The cobalt blue is so rich and lively that it predominates in some measure over every other colour, and masks many so that they can hardly be perceived; it is also most easily obtained. To bring it out, however, in all its beauty, the other tints must be removed as much as possible, and the cobalt itself should be tolerably pure. This metal is associated in the best known ores with a considerable number of foreign substances, as iron, arsenic, copper, nickel, and sulphur, and it is difficult to separate them completely; but for enamel blues, the oxide of cobalt does not require to be perfectly free from foreign metals; the iron, nickel, and copper, being most prejudicial, should, however, be carefully eliminated. This object may be most easily attained by dissolving the ore in nitric acid, evaporating the solution to a sirupy consistence, to expel the excess of acid and separate a portion of arsenic. It is now diluted with water, and a solution of carbonate of soda is dropped slowly into it with brisk agitation, till the precipitate, which is at first of a whitish-grey, begins to turn of a rose-red.

Whenever this colour appears, the whole must be thrown on a filter, and the liquid which passes through must be treated with more of the carbonate of soda, in order to obtain the arseniate of cobalt, which is nearly pure.

Metallic fluxes are not the most suitable for this tint, because they always communicate a tinge of greater or less intensity, which never fails to injure the purity of the blue. Nitrate of soda is a useful addition, as it keeps the oxide at the maximum of oxidation, in which state it produces the richest colour.

Black Enamel.—Black enamels are made with binoxide of manganese or protoxide of iron (ferrous oxide), to which more depth of colour is given with a little cobalt. Clay alone melted with about a third of its weight of protoxide of iron gives a fine black enamel.

Violet Enamel.—The binoxide of manganese, in small quantity by itself, furnishes, with saline or alkaline fluxes, an enamel of a very fine violet hue; and variations of shade are easily had by modifying the proportions of the elements of the coloured frit. The great point is to maintain the manganese in the state of binoxide, and, consequently, to avoid placing the enamel in contact with any substance attractive of oxygen.

Enamelling on Iron.—The process most commonly used was devised by CHARLES HENRY PARIS of France; it consists in coating articles made of wrought iron with glass or vitreous matter, so as to keep off the atmosphere and other fluids and matters, which would cause an oxidation of the metal. Articles made of sheet or of wrought iron, whether in the form of vessels, trays, pipes, or otherwise, are first to have their surfaces cleansed by dilute acid, and dried; then a coating of gum-arabic, dissolved in water, is to be applied to the surface by a brush or otherwise; then by means of a sieve the fine powder of glass or vitreous matter is to be sifted all over the surfaces. The article is next introduced into an oven heated to 212° to 300° Fahr., and, when dry, is removed into another chamber, and elevated to a bright red heat till the glass or vitreous matter is melted on the surface, which can readily be seen by looking through a hole in the cover of the recipient. The articles are then removed into a close chamber, with a cover to exclude as much as possible the action of the air, till the whole is cooled down. If, on examination, the coating is imperfect, another is to be added in like manner to the first.

The following is the vitreous mixture:—130 parts of flint glass reduced to powder, 20½ parts of carbonate of soda, and 12 parts of boracic acid. These matters being intimately mixed, are to be placed in a glassmaker's crucible, melted, then drawn off, cooled, reduced to an impalpable powder, which is to be sifted through a fine sieve—say about 60 holes to the inch—and this powder is to be applied in the dry state as before described. It is important, in preparing the glass or vitreous substance, that it should be free from foreign impurities; for this reason steel stampers are employed for crushing the matters into a powder, and before employing the crucible PARIS causes it to be coated with glass, by applying gum-water to its inner surface, and then dusting over the powder of glass; and, after the same has been well dried, heated gradually up to the point of fusion of the glass, by which the surface of the crucible will be coated, and will thus, when used, prevent impurities from the crucible getting mixed up with the glass or vitreous mixture. If it be desired that the surfaces of the iron should have coloured glass or vitreous matter applied thereto, then it is first to be coated with the mixture above named, and afterwards a further coating of coloured glass is applied to the surfaces, as may be desired.

Enamelling on other metals is generally performed on plates of gold or of copper, but seldom on silver, as it is apt to occasion flaws in the surface of the enamel. Copper is the metal most generally used for this purpose, coated with the white enamel, on which painting is executed with colours which are melted in the fire, where they take a brightness and lustre like that of glass. This kind of painting is particularly prized for its peculiar brilliancy and vivacity, which is permanent, the force of its hues not being liable to be effaced or sullied by time, as in other painting, and continuing always as fresh as when it came out of the workman's hands. This method of painting is almost entirely confined to miniature; larger works being liable to accidents in the operation.

The most perfect kind of enamelling is practised on plates of gold, the other metals being less pure. Copper, for instance, sometimes scales with the application; and silver turns the yellow white. To obviate the cracking of the enamel, the plates are generally made a little round or oval, and rather thin. The operation is usually commenced by laying on a couch of white enamel on both sides of the plate, which prevents the metal from swelling and blistering; and this first layer serves for the ground of all the other tints. The next step is to draw out exactly the subject to be painted with basic sulphate of the sesquioxide of iron, mixed with oil of lavender, marking all parts of the design very lightly with a pencil. After this the colours—very finely ground, and mixed with the oil somewhat thick—are to be laid on, attention being given to the mixtures and colours which agree to the different parts of the subject.

When the colours are all laid, the painting is to be gently dried over a slow fire to evaporate the oil, and the colours are afterwards melted to incorporate them with the enamel, making the plate red hot in a fire such as enamellers use. Afterwards, the painting may be retouched, and is then to be committed a second time to the fire, and so on till the work be completed.

ETHER.—*Ether*, French; *Aether*, German.—The volatile inflammable liquid obtained by distilling a mixture of alcohol with sulphuric acid was undoubtedly amongst the secrets of the alchemists or earlier chemists, as is evinced by various passages in their writings. It is said to have been known to RAYMOND LULLY, and the method of preparing it is given in the dispensatory of VALERIUS CORDUS in 1540, from which it was copied by CONRAD GESNER into his "Thesaurus Euonymi de Remediis Secretis," published in 1552, who called it "Oleum Vitrioli Dulce." BASIL VALENTINE and PARACELSUS appear to have been acquainted with it, and BOYLE also mentions it; but it was not until 1730 that the attention of chemists was directed to it, for in that year Dr. FROBENIUS presented a quantity of it to the Royal Society, and several experiments were made to ascertain its chief properties In his paper he gives it the name of *ether*, instead of *naphtha*, by which it was known amongst the German chemists.

These observations apply to ordinary ether, or, as it is sometimes called, "sulphuric ether;" but the term *ether* is now used to designate, not only the volatile inflammable liquid obtained by the action of sulphuric acid on alcohol, and various other substances whose properties and mode of formation are strictly analogous to it, but also to the ethereal salts or "compound ethers," a class of bodies, some of which exist naturally in fruits, and many more may be obtained by the mutual reaction of alcohols and various acids. Most of these latter compounds have a fragrant odour; the peculiar flavours of the pineapple, melon, strawberry, and other fruits, depending on the presence of a minute quantity of one or more of these ethers.

ETHER, *Sulphuric Ether*, or *Ethylic Oxide* $(C_2H_5)_2O$.—This is the best known and most important member of a large class of perfectly analogous bodies, which are related to the coresponding alcohols in a manner precisely similar to that in which ether is related to ordinary alcohol. Ether is formed in a variety of chemical reactions, but in nearly all cases it may be ultimately traced to the action of an acid on the alcohol. The principal methods of formation are the following:—

1. The action of ethyl iodide on sodium ethylate, as represented in the equation—

$$\overset{\text{Ethyl iodide.}}{C_2H_5I} + \overset{\text{Sodium ethylate.}}{C_2H_5.ONa} = \overset{\text{Ether.}}{(C_2H_5)_2O} + \overset{\text{Sodium iodide.}}{NaI.}$$

2. On heating alcohol with ethyl bromide or iodide to 200° C.

$$\overset{\text{Ethyl iodide.}}{C_2H_5I} + \overset{\text{Alcohol.}}{C_2H_5.OH} = \overset{\text{Ether.}}{(C_2H_5)_2O} + \overset{\text{Hydriodic acid.}}{HI.}$$

3. By heating alcohol with hydrochloric, hydrobromic, or hydriodic acid to about 240° C. Here ethyl chloride, bromide, or iodide is first formed thus:—

$$\overset{\text{Alcohol.}}{C_2H_5.OH} + \overset{\text{Hydriodic acid.}}{HI} = \overset{\text{Ethyl iodide.}}{C_2H_5I} + \overset{\text{Water.}}{OH_2}$$

and the ethyl iodide then acts on another portion of the alcohol, as in 2.

4. By heating ethyl iodide with water to 200° C. In this case part of the ethyl iodide is resolved, by the action of the water, into hydriodic acid and alcohol.

$$\overset{\text{Ethyl iodide.}}{C_2H_5I} + \overset{\text{Water.}}{OH_2} = \overset{\text{Alcohol.}}{C_2H_5.OH} + \overset{\text{Hydriodic acid.}}{HI}$$

and the alcohol then acts on the remainder of the ethyl iodide, as in 2

In a similar manner certain metallic chlorides, when heated to a high temperature with alcohol, convert it into ether; no doubt ethyl chloride is first formed, which reacts with a portion of the alcohol, forming ether in the manner previously explained.

These processes, although interesting from a theoretical point of view, are not employed for the manufacture of ether, which is invariably obtained on the large scale by the action of concentrated sulphuric acid on alcohol. The action which takes place is rather complicated, but will be fully discussed hereafter.

Preparation of Ether.—PHILLIPS gives the following directions:—To 16 ozs. of sulphuric acid add the same quantity of rectified spirit, and distil over about 10 fluid ozs.; or continue the operation until the contents of the retort begin to froth up, or the residual liquid has a strong odour of sulphurous acid; mix the two products, and if a light and heavy fluid appear, separate them; add caustic potash to the former as long as it dissolves; separate the ether from the alkaline solution, and distil about nine-tenths of it, which may be preserved for use. It will have a specific gravity of 0·75. Preparing ether upon a larger scale, it was found that 14 parts of alcohol (spec. grav. 0·820) mixed with the same quantity of sulphuric acid (density 1·80) and submitted to distillation, yielded about 8 parts of an impure product (spec. grav. 0·770): 7 parts of alcohol were then added to the residuum, and nearly 8 parts more of impure ether drawn over. These distillates, when mixed, had a density of about 0·782, and when rectified by distillation over carbonate of potassium afforded 10 parts of ether, having a specific gravity of 0·735, and about 3½ parts of ethereal spirit, which was employed, instead of an equal quantity of alcohol, in the succeeding operation.

This method of preparing ether by the distillation of a mixture of alcohol and sulphuric acid has great disadvantages, since etherification only takes place within a certain rather limited range of temperature. The consequence of this is, that when a mixture, say, of equal parts of alcohol and sulphuric acid is heated, pure alcohol first comes over, which, as the temperature of the liquid in the retort gradually rises until it attains the point at which etherification commences, is succeeded by a mixture of alcohol, water, and ether. As the distillation proceeds, however, the temperature still continues to rise, so that at last the formation of ether ceases, and ethylene or olefiant gas, sulphurous anhydride, and oily compounds of disagreeable odour, are the sole products. This inconvenience has been entirely obviated by the process devised by BOULLAY, which, moreover, has the advantage of being continuous. A mixture of sulphuric acid and alcohol is made in such proportions that it will boil at the temperature at which etherification takes place readily, and then a regulated stream of alcohol is allowed to flow into the boiling mixture at such a rate that it boils constantly at the same temperature; the distillate in this case consisting almost entirely of ether and water, mixed with a very little alcohol and oil of wine.

BOULLAY's method, with slight modifications, is now universally adopted in the preparation of ether, whether on the large or small scale. A mixture of 9 parts of sulphuric acid with 5 of alcohol of 90 per cent. is introduced into a flask, through the cork of which passes an exit tube connected with a good condensing arrangement, a thermometer for regulating the temperature, and a second tube, which is connected with a reservoir of alcohol, and the lower end of which, drawn out so as to contract its diameter somewhat, dips into the liquid to about two-thirds of its depth. This tube is provided with a stopcock, so as to regulate the flow of the alcohol. Heat is applied by means of a sand bath; and as soon as the liquid begins to boil, and the thermometer indicates a temperature of about 140° C. (284° Fahr.), the stopcock connected with the reservoir is opened, and a gentle stream of alcohol is allowed to run into the flask, the flow being regulated so as not to check the boiling, and to maintain the temperature constant, as near as possible. When about 35 parts of alcohol of the above strength have been passed into the boiling liquid, the operation should be stopped, as the sulphuric acid becomes too dilute to etherify the alcohol rapidly and effectually. The alcohol which remains in the mixture in the retort may be recovered by adding water and distilling. According to MOHR, the celebrated German pharmaceutist, it is better to begin the operation with a mixture of alcohol and sulphuric acid in the proportion of 3 of the former to 4 of the latter. This begins to boil at 125° (257° Fahr.), and the distillation is continued until the thermometer marks 135° (275° Fahr.), when the stopcock is opened to allow the alcohol to flow into the flask; the operation then being continued in the manner just described.

The first portions of the distillate consist of two layers, the upper one of which is ether, containing a little alcohol and water, and the lower one water, holding alcohol and ether in solution. As the distillation continues, the upper layer becomes comparatively small, until at last only one liquid is observed; much more alcohol passing over. The product now also contains sulphurous anhydride, acetic acid, and a little oil of wine.

The arrangement shown in the accompanying wood-cut (Fig. 1) is convenient where small quantities of ether are required. It consists of a glass tubulated retort, A, heated by means of a sand bath, and connected with a LIEBIG's condenser, C. Through the cork in the tubulure a thermometer passes, and also a narrow lead or glass tube, *a*, dipping into the liquid in the retort. B is the reservoir for the alcohol, the flow of which is regulated by means of the stopcock, *b*. The flask, D, serves to receive the distillate as it comes over, whilst E represents a vessel containing a supply of cold water for the condenser, C. The mixture of alcohol and acid should be made in an iron vessel, surrounded by cold water. As great heat is evolved during the act of mixing, it is best to first place the alcohol in the vessel, and then cautiously pour in the sulphuric acid down the side of the vessel, or, better still, by means of a funnel with a long neck reaching to the bottom. By this means the acid forms a layer beneath the alcohol, and may be slowly and carefully mixed by gently stirring it with a glass rod or porcelain spatula, taking care that the temperature does not rise to any great extent.

Ether is generally manufactured on the large scale in an iron retort lined with lead, the apparatus being similar to that shown in Fig. 2. A is an iron retort lined with lead, placed on a layer of sand on a hot plate heated by a suitable furnace, B, the door of which should be in another room than the distilling apparatus. This retort is closed by a head, D, connected with a worm, F, in the worm-tub, E, through which a current of cold water flows. The retort is furnished with a gauge, *c*, for observing the level of the liquid in the interior; a thermometer; and a small opening at the bottom for discharging the spent acid, ordinarily closed by a well-fitting stopper.

Fig. 1.

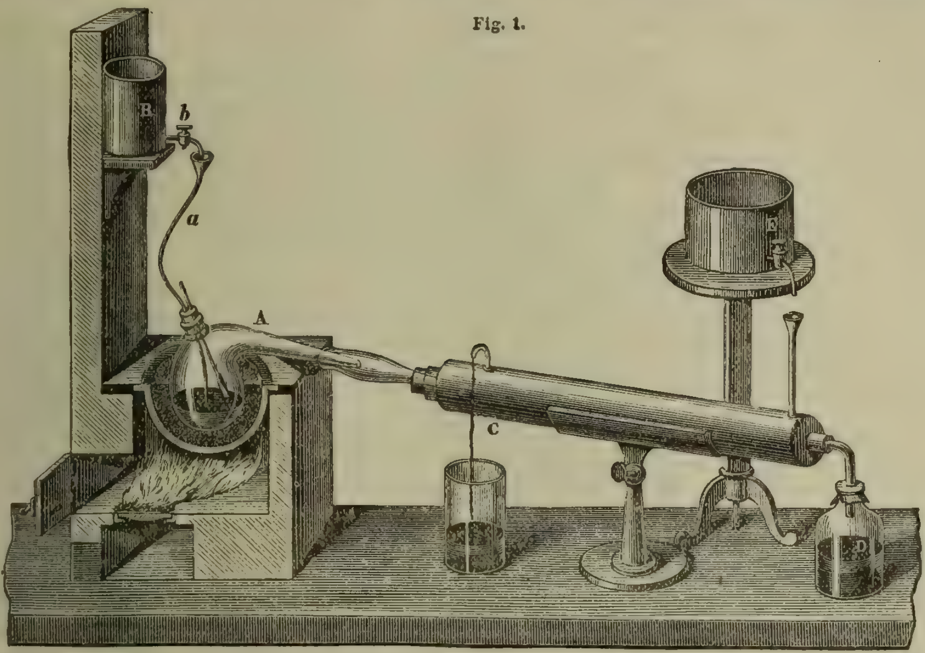
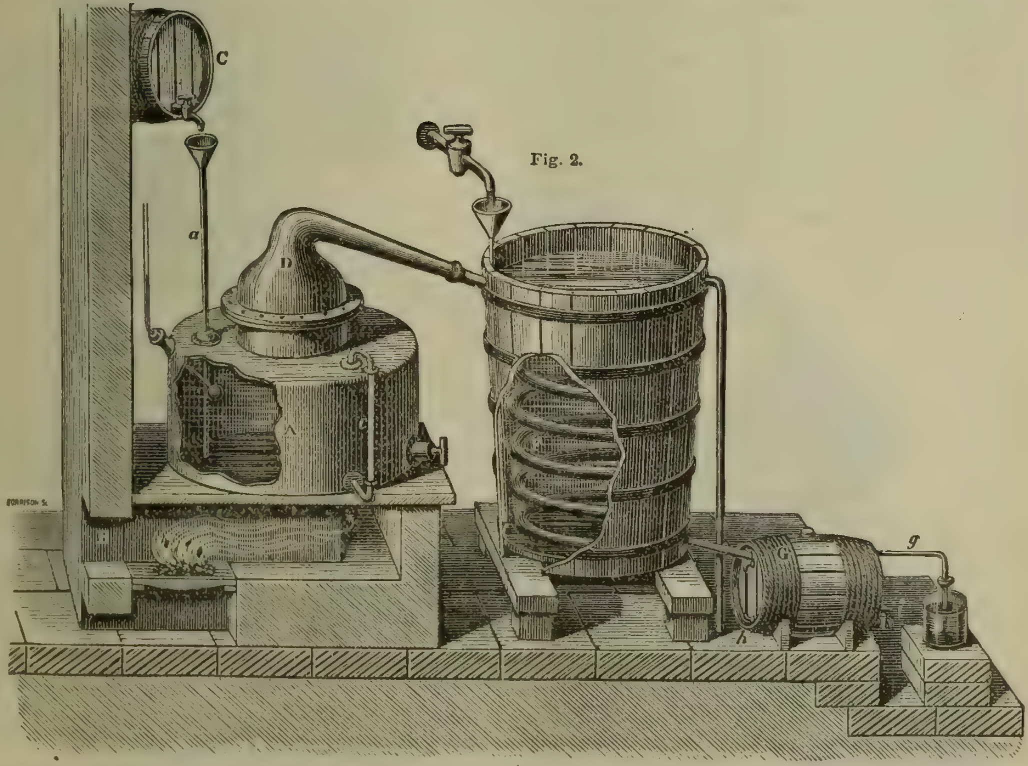


Fig. 2.



The head, D, being removed, the retort is filled about one-half or two-thirds full of the acid mixture, the head replaced and connected with the worm, taking especial care that all the joints are perfectly tight. The other end of the worm is connected with the cask, G, to receive the distillate. This, like the retort, is furnished with a gauge, *h*, and stopcock, *i*, for drawing off the crude ether. *g* is a safety tube dipping into alcohol contained in the flask. The apparatus being charged, a fire is lighted to heat the contents of the retort; and as soon as the thermometer shows that the liquid has attained the proper temperature, 135° C. (275° Fahr.), a stream of alcohol is allowed to flow in from the cask, C, through the tube, *a*, which reaches nearly to the bottom of the retort. As an ordinary mercurial thermometer is somewhat fragile and delicate for ordinary rough manufacturing purposes like the present, it may be advantageously replaced by an oil thermometer, consisting of a stout glass tube, with a good sized bulb blown on the end, and filled with a non-drying oil, which has previously been strongly heated to expel moisture. The tube may then be exhausted by means of an air pump, and hermetically sealed, or simply closed with a plug of cotton wool, two marks being made on the tube at the temperatures corresponding to 130° C. (266° Fahr.) and 140° C. (284° Fahr.).

The distillation is continued uninterruptedly until the proposed quantity of alcohol has been run into the retort, the temperature being constantly maintained between 130° C. and 140° C. (266° and 284° Fahr.), but owing to the volatile nature of the product and its great inflammability, the utmost care must be taken to prevent accident. This may occur, not only from bringing a light near the apparatus, but also from the heavy ether vapour flowing along the ground until it reaches some furnace or fire at a distance, when an explosion inevitably occurs, often of the most dangerous nature. On this account it is better, instead of employing an open furnace, to heat the retort by means of a leaden coil through which superheated steam or a high boiling point liquid, like coal-tar phenol, is made to flow, thus obviating the necessity of having a fire in the immediate vicinity of the apparatus. In order to free the product from any sulphurous acid it may contain, it is agitated with milk of lime or a solution of soda, and after separating it from the aqueous layer it is rectified. The aqueous liquid also yields a further quantity of ether when heated.

Fig. 3.

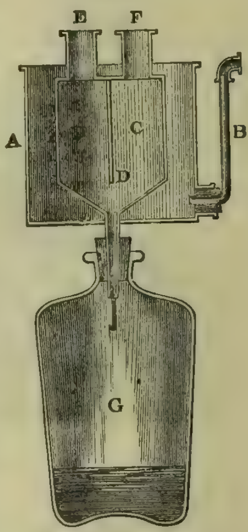
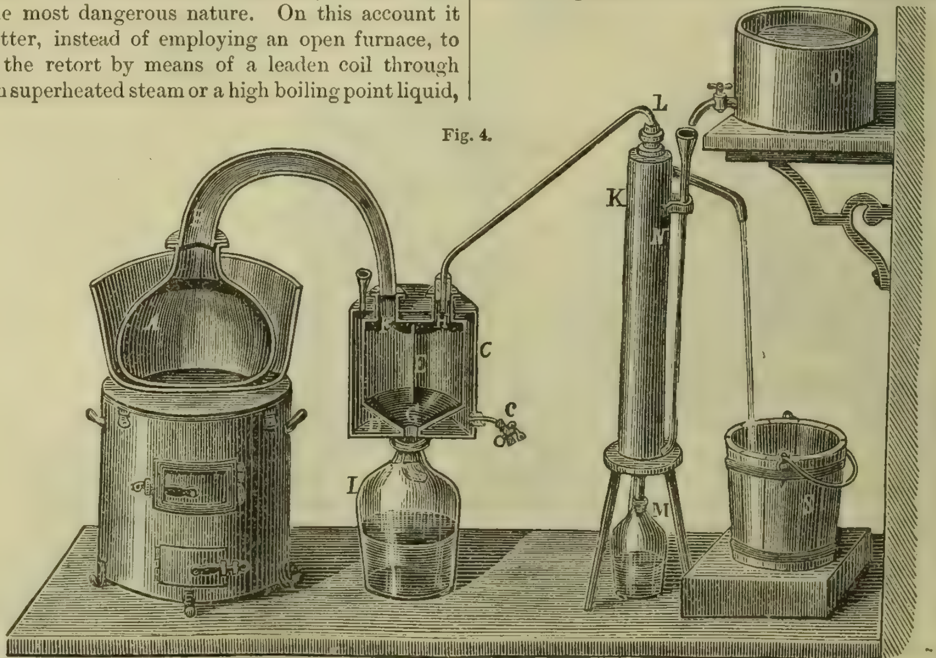
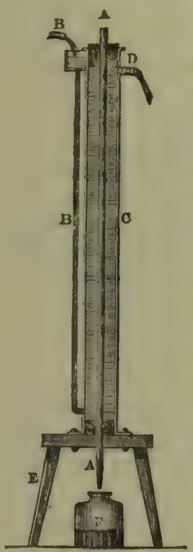


Fig. 4.



Rectification of Ether.—In rectifying commercial ether by distilling it in the ordinary way, nearly pure ether passes over at first, amounting to about one third of the whole, then a mixture of ether and alcohol, afterwards dilute alcohol containing oil of wine, and finally water. It is only by frequently observing the specific gravity of the distillate that it can be ascertained when pure ether ceases to come over unmixed with alcohol; and there is considerable difficulty in recovering both the alcohol and the ether remaining in the residue in the retort. Mohr, however, has devised an apparatus, Fig. 3, by the use of which commercial ether is made to yield at one operation, not only all the pure ether it contains, but at the same time the spirit is left almost free from ether. This is effected by passing the vapour arising from the boiling crude ether through a condenser, C D, kept at a temperature of 38° C. (100° Fahr.) by means of warm water; here the alcohol is condensed, and runs into the vessel, G,

Fig. 5.



whilst the vapour of the ether, which boils at 35·6° C. (96° Fahr.) passes on, and is condensed by means of cold water. The accompanying illustration, Fig. 4, shows Mohr's arrangement. A is a copper retort heated by means of a water bath, and connected by the adapter, B, with the alcohol condenser, C. This is also made of copper, and consists of two parts, an exterior vessel, D, filled with warm water, kept at a constant temperature by pouring in fresh when necessary through the funnel, and withdrawing the excess at *c*. The ether vapour entering at F, is obliged to pass down to G, on one side of the partition, E, and then makes its exit at H, having parted with its alcohol by being cooled to 38° C. (100° Fahr.), in contact with the comparatively cool sides of the copper vessel; this alcohol, containing a little ether in solution, drips through D, into the jar, I, provided for its reception. The ether vapour then passes through the condensing tube, L, of the Liebig's condenser, K, and flows into the bottle at M. Fig. 5 shows this condenser in cross section. It consists of a glass tube, A A, surrounded by a brass tube, C, closed at each end by a cork perforated to allow the glass tube to pass through. A small tube, B, conveys cold water to the bottom of the annular space between the two tubes, whilst the hot water flows out at the top through D. The apparatus is supported on a three legged stand, E, so as to admit of a vessel, F, being placed underneath to receive the condensed liquid.

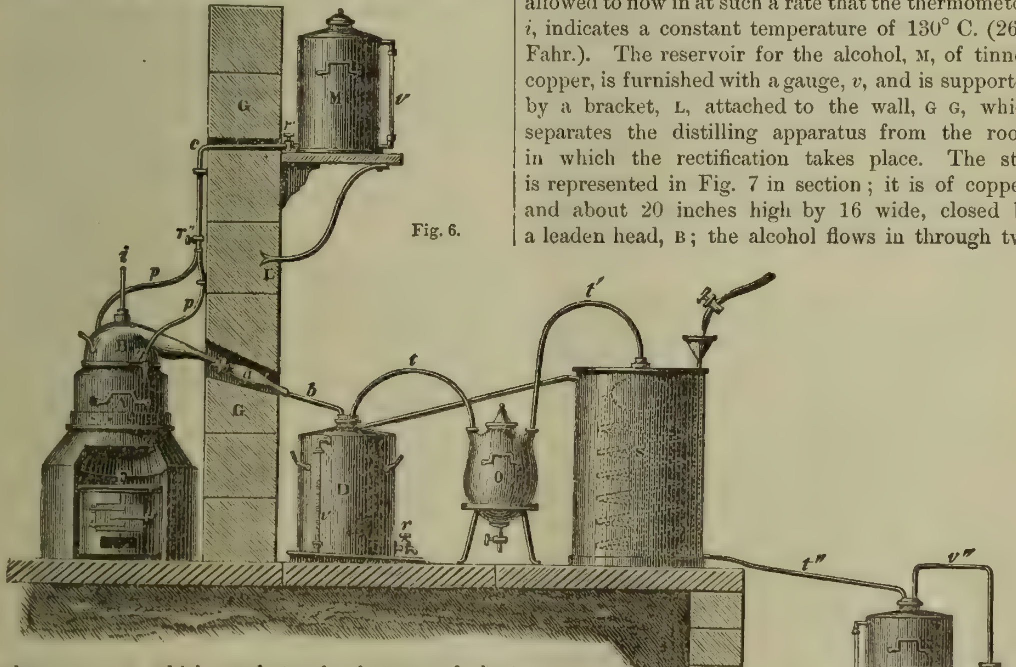


Fig. 6.

The ordinary method of first preparing ether, and subsequently submitting it to rectification, involves two distinct processes, causing some loss in the pouring of the liquids from one vessel to another, besides requiring a considerable amount of manual labour. This may be entirely got rid of by the use of an ingenious apparatus invented by Soubeiran, somewhat similar in principle to the stills now employed in the manufacture of alcohol. By his method, pure ether may be obtained from alcohol at one operation, but the apparatus is more complicated than that usually employed, and far more costly. A mixture of 30 lbs. of sulphuric acid with 20 of alcohol of 85 per cent is run into the still, A, Fig. 6, and heated as rapidly as possible to 130° C. (266° Fahr.) by means of the furnace, F. When this temperature is reached, the stopcocks, *r* and *r*″, are opened, and a stream of alcohol of 92 per cent. allowed to flow in at such a rate that the thermometer, *i*, indicates a constant temperature of 130° C. (266° Fahr.). The reservoir for the alcohol, M, of tinned copper, is furnished with a gauge, *v*, and is supported by a bracket, L, attached to the wall, G G, which separates the distilling apparatus from the room in which the rectification takes place. The still is represented in Fig. 7 in section; it is of copper, and about 20 inches high by 16 wide, closed by a leaden head, B; the alcohol flows in through two tubes, *p q*, *p q*, which reach to the bottom of the vessel: at *d d* is a perforated plate of thick copper, the object of which is to assist the perfect mixing of the alcohol with the acid mixture. A wide copper tube, *f f*, reaching to the bottom of the vessel, and open at both ends, serves for the introduction of a long thermometer, *i*.

The neck of the retort is joined by means of the adapter, *a* (Fig. 6), and the tube, *b*, with the first condenser, D, also of copper, and which is kept warm by allowing the water from the worm-tub, S, to flow over the outside; it is provided with a gauge, *v*, for ascertaining the amount of liquor in the interior, and with a stopcock, *r*, for drawing it off when required. Here the aqueous vapour is condensed, and also almost the whole of the unattacked alcohol, whilst the ether passes on in the state of vapour through the tube, *t*, to the purifying vessel, O, shown in section in Fig. 8. This is filled with fragments of wood charcoal saturated with a solution of caustic soda, which serves not only to remove the sulphurous anhydride always produced in larger or smaller quantity during the reaction, but also absorbs the oil of wine. The vessel, O, being exposed freely to the air, the small quantities of alcohol and water which have escaped condensation in D are retained here, whilst the now pure ether passes on through *t′*, and is condensed by the worm in the tub, S, supplied by a stream of cold water. The liquid ether runs out through *t″* into the receiver, V. A safety tube, *v″*, dipping into water or alcohol, cuts off all communication between the external air and the interior of the apparatus.

Fig. 7.

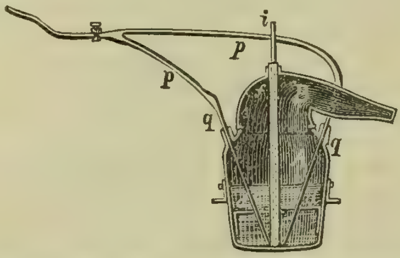
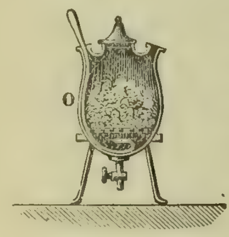


Fig. 8.



The use of a copper body to the still instead of a leaden one possesses great advantages, as it can be made much thinner than when of lead; and copper being an excellent conductor of heat, a change in the amount of heat produced in the furnace is rapidly communicated to the contents of the still. The importance of this will be at once appreciated when it is considered that etherification only takes place rapidly and efficiently within a comparatively small range of temperature; moreover, the acid mixture attacks the copper but very slightly at that temperature. With an apparatus such as described above, 23 to 25 gals. of alcohol may be converted into pure ether in the course of twelve hours.

Theory of the Formation of Ether.—Several processes by which this compound is formed have been already noticed, but the one which is specially interesting, whether from a purely scientific point of view or from its technical importance, is the action of sulphuric acid on alcohol. At first sight the reaction would seem to be one merely of dehydration, due to the great affinity of the sulphuric acid for water, and represented by the equation—

$$\overset{\text{Alcohol.}}{2C_2H_5.OH} = \overset{\text{Ether.}}{(C_2H_5)_2O} + \overset{\text{Water.}}{OH_2}.$$

A little consideration, however, will at once show that this is not the case, for not only does the process of etherification take place at a comparatively high temperature, but water distils over simultaneously with the ether, and is not retained by the sulphuric acid, as it would be on the supposition that the reaction is one of dehydration. It is to WILLIAMSON that we owe the explanation of the successive changes which take place in the ordinary continuous process for the production of ether. By means of an admirably conceived series of experiments he showed that sulphuric acid acts on alcohol to form hydric ethyl sulphate, or sulphovinic acid, with elimination of water,

$$\overset{\text{Alcohol.}}{C_2H_5.OH} + \overset{\text{Sulphuric Acid.}}{H_2SO_4} = \overset{\text{Sulphovinic Acid.}}{C_2H_5.HSO_4} + \overset{\text{Water.}}{OH_2},$$

and that this sulphovinic acid, at the temperature at which etherification takes place, acts on a second molecule of alcohol with formation of ether and regeneration of sulphuric acid, thus:—

$$\overset{\text{Sulphovinic Acid.}}{C_2H_5.HSO_4} + \overset{\text{Alcohol.}}{C_2H_5.OH} = \overset{\text{Ether.}}{(C_2H_5)_2O} + \overset{\text{Sulphuric Acid.}}{H_2SO_4}.$$

The regenerated sulphuric acid then acts on a third molecule of alcohol to again form sulphovinic acid, which in its turn is decomposed, and so on.

It will be evident that, if these reactions actually occur as represented, when we substitute for sulphovinic acid a similar acid containing a different alcohol radicle (amyl-sulphuric acid, for example), a mixed ether should be produced.

$$\overset{\text{Amyl-sulphuric Acid.}}{C_5H_{11}.HSO_4} + \overset{\text{Alcohol.}}{C_2H_5.OH} = \overset{\text{Ethyl-amyl Ether.}}{\left.\begin{matrix}C_2H_5\\C_5H_{11}\end{matrix}\right\}O} + \overset{\text{Sulphuric Acid.}}{H_2SO_4}.$$

On making the experiment with hydric amylic sulphate (amyl-sulphuric acid) and alcohol, WILLIAMSON found the result entirely in accordance with what might be predicted from theoretical considerations. In like manner a mixed ether was obtained on causing sulphuric acid to act on a mixture of amylic alcohol and ordinary alcohol.

"Methylated ether" is now largely manufactured in England from methylated spirit by the ordinary continuous process; and as this spirit is a mixture of ordinary ethylic alcohol with a comparatively small amount of methylic alcohol, the ether prepared from it might be expected to consist of ordinary ether, mixed with a small quantity of the compound methyl ethyl ether $(C_2H_5)(CH_3)O$. Some years ago Dr. HOFMANN, as he was rectifying a large quantity of this ether over lime, observed that an exceedingly volatile liquid came over first, before the ether itself began to distil. On collecting and examining this it was found to be methyl ethyl ether.

WILLIAMSON's experiments were confirmed by those of GRAHAM. This chemist found that on heating sulphovinic acid with water to 140° C. (284° Fahr.), alcohol was formed; but that if alcohol was substituted for the water, the product consisted of ether, the reactions being perfectly parallel.

$$\overset{\text{Sulphovinic Acid.}}{C_2H_5.HSO_4} \quad + \quad \overset{\text{Water.}}{H.OH} \quad = \quad \overset{\text{Alcohol.}}{\left.\begin{matrix}C_2H_5\\H\end{matrix}\right\}O} \quad + \quad \overset{\text{Sulphuric Acid.}}{H_2SO_4}$$

$$\overset{\text{Sulphovinic Acid.}}{C_2H_5.HSO_4} \quad + \quad \overset{\text{Alcohol.}}{C_2H_5.OH} \quad = \quad \overset{\text{Ether.}}{\left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right\}O} \quad + \quad \overset{\text{Sulphuric Acid.}}{H_2SO_4}$$

REYNOSO found that not only does sulphuric acid effect the etherification of alcohol, but that many sulphates possess the same property. Magnesium, zinc, cadmium, cobalt, and ferrous sulphates act readily; uranium oxide and acid sodium sulphate also form a large quantity of ether. Alcohol is completely etherified by aluminium sulphate and the alums at 200° C. (392° Fahr.), without any formation of permanent gas. Copper and nickel sulphates form ether, but they are at the same time decomposed. In all these cases it is probable that sulphovinates, or free sulphovinic acid, and a basic salt are first formed, which then reacts with the alcohol in the manner just described.

Ordinary ether, containing water, when kept for some time exposed to light in a bottle only partially filled with the liquid, causes the production of hydrogen peroxide, as may be readily shown by agitating a portion of the liquid with a dilute solution of chromic acid. The ether immediately acquires the beautiful blue colour so characteristic of perchromic acid. If perfectly pure ether is agitated with water, the aqueous liquid does not acquire the property of showing the iodoform reaction when treated with iodine and potash; the smallest trace of alcohol, however, is sufficient to give the yellow colour. This purification may be effected by drying the ether and then distilling it two or three times from metallic sodium cut in thin slices.

Composition of Ether.—When ether is submitted to analysis in the ordinary way, it is found to be composed of carbon, oxygen, and hydrogen, in the proportions represented by the formula $C_4H_{10}O$—

C_4.............. = 48 .... 64·87
H_{10}.............. = 10 .... 13·51
O................ = 16 .... 21·62
74 100·00

And from a consideration of the various methods by which it is produced, and the changes which it undergoes, it has been ascertained that it bears precisely the same relation to alcohol that the oxides of the monad metals, such as potassium, have to the hydrates, thus—

Alcohol.	Potassium Hydrate.	Ether.	Potassium Oxide.
$C_2H_5.OH$	$K.OH$	$(C_2H_5)_2O$	K_2O

Here the hypothetical radicle ethyl, C_2H_5, plays the same part as the metal potassium, alcohol being the hydrate of ethyl, and ether the oxide.

In the same way the various ethereal salts, such as ethyl acetate, $C_2H_5.C_2H_3O$; ethyl nitrate, $C_2H_5.NO_3$; ethyl chloride, C_2H_5Cl; ethyl iodide, C_2H_5I, &c., are strictly analogous in their structure to potassium acetate, KC_2H_3O; potassium nitrate, KNO_3; potassium chloride, KCl; and potassium iodide, KI.

Properties of Ether.—Ether is a highly volatile, transparent, colourless, limpid liquid, of a peculiar penetrating and agreeable odour, and a pungent and sweetish taste. It is neither acid nor alkaline; has a high refractive power in regard to light; is a non-conductor of electricity; and is sparingly soluble in water, 9 volumes of the latter dissolving 1 of ether. It is dissolved by alcohol in all proportions. It removes bichloride of mercury, terchloride of gold, tetrachloride of platinum, and the sesquichloride of iron from their aqueous solutions, when agitated with them. Bromine and iodine are readily soluble in ether; but the solutions, by keeping, undergo decomposition. Sulphur and phosphorus are sparingly dissolved by it. The ethereal solution of the former is luminous in the dark when poured on hot water. It dissolves the volatile oils, most of the fatty and resinous substances, some of the vegetable alkalies, urea, gun-cotton—forming collodion—and caoutchouc.

Ether boils at 96° Fahr. (35·6° C.), and produces, by its evaporation, a great degree of cold. At the temperature 62·4° Fahr., the vapour of ether balances a column of mercury 15 inches high, or half the weight of the atmosphere. When cooled to minus 24° Fahr. it begins to crystallize in brilliant white plates; and at minus 47° it becomes a white crystalline solid. When its vapour is made to traverse a red-hot porcelain tube, it deposits within it one-half per cent. of charcoal, and there is condensed in the receiver one and two-thirds per cent. of a brown oil, partly in crystalline scales, and partly viscid. The former portion is soluble in alcohol, but the latter only in ether.

Ether takes fire readily, even at some distance from a flame, and it should not, therefore, be poured from one vessel to another in the neighbourhood of a light. It may be likewise set on fire by the electric spark. It burns entirely away with a bright smoky flame. When the vapour of ether is mixed with ten times its volume of oxygen, it ignites with a violent explosion, absorbs six times its bulk of oxygen, and produces four times its volume of carbonic acid gas.

SCHÖNBEIN found that a little pure ether put into a bottle filled with oxygen or atmospheric air, and exposed to diffused light, the bottle being occasionally shaken, had partially changed its nature after the lapse of four months. Although producing no action upon blue litmus paper, it discharged the colour of a solution of indigo, converted phosphorus when immersed in it into phosphorous acid, eliminated iodine from iodide of potassium, changed protosulphate of iron to basic and sesquisulphates, transformed ferrocyanide into ferricyanide of potassium, sulphite of lead into sulphate, &c.

PEREIRA says that the operation of ether upon the system is analogous to that of alcohol, but much more rapid and transient. *Swallowed in moderate doses*, it produces a powerful impression on the mouth, throat, and stomach; allays spasm, and relieves flatulence; but according to some observers it augments neither the heat of the body nor the frequency of the pulse. Its first effects on the cerebral functions are those of an excitant, but the subsequent ones are of a depressing nature. *In somewhat larger doses*, it produces intoxication like that caused by alcohol. *In excessive doses* it occasions nausea, a copious flow of saliva, giddiness, and stupefaction.

The long and habitual use of ether diminishes the effect of this substance over the system, and therefore the dose must be proportionally increased. Dr. Christison mentions the case of an old gentleman who consumed 16 ozs. every eight or ten days, and had been in the habit of doing so for many years. Yet, with the exception of an asthma, for which he took the ether, he enjoyed tolerable health. Bucquet, who died of scirrhus of the colon, with inflammation of the stomach and of the intestines generally, imbibed before his death a pint of ether daily, to alleviate his excruciating pains.

When the vapour of ether, sufficiently diluted with atmospheric air, is *inhaled*, it causes irritation about the epiglottis, a sensation of fulness in the head, and effects analogous to those caused by the protoxide of nitrogen—laughing gas; moreover, persons peculiarly susceptible of the action of the one, are also powerfully affected by the other. If the air be too strongly impregnated with ether stupefaction ensues. In one case this state continued, with occasional periods of intermission, for more than thirty hours; for many days the pulse was so much lowered that considerable fears were entertained for the safety of the patient. In another case, an apoplectic condition, which continued for some hours, was produced. The anæsthetic properties of this vapour are well known. They are similar to those of chloroform, which has almost entirely superseded it. In surgical operations it has been much used for the purpose of destroying sensibility; but preference is generally given to chloroform. [Anæsthetics.]

The effects of ether on animals have been determined by Orfila, who found that half an ounce introduced into the stomach of a dog, with the œsophagus tied, caused attempts to vomit, diminished muscular power, produced insensibility, and in three hours death. Three drachms and a half injected into the cellular tissue of the thigh caused death on the fourth day. Jager found that half an ounce of ether acted as a fatal poison to a crane; at the end of forty-eight hours its odour could be readily detected in the body. He made similar experiments on pigeons and ducks. One of the last-mentioned animals took altogether an ounce of ether, yet was not dead at the end of twenty-four hours.—Pereira.

Gorup-Besanez has published some experiments upon the composition of the blood before and after the inhalation of ether. He invariably found an increase of water and diminution of blood corpuscles.

Uses.—In medicine, ether is principally valuable as a speedy and powerful agent in spasmodic and painful affections, not dependent on local vascular excitement, and which are accompanied by a pale, cold skin, and a small, feeble pulse. If administered during a paroxysm of spasmodic asthma, it generally gives relief, but has no tendency to prevent the recurrence of attacks. In cramp of the stomach, flatulent colic, &c., its happy effects are well established. In the latter stages of continued fever, ether is sometimes admissible. Desbois de Rochefort administered it successfully in intermittent fevers. Headache, of the kind popularly called nervous, that is, unconnected with vascular excitement, is speedily relieved by ether. In flatulence of the stomach it may be taken in combination with some aromatic water. As an antidote against sea-sickness, it should be swallowed in a glass of white wine. Durande recommends a mixture of 3 parts of ether and 2 of oil of turpentine as a solvent for biliary calculi. Bourdier employed ether, in infusion of male fern, to expel tape-worm. In faintness and lowness of spirits, it is a popular remedy. It has been employed in cases of poisoning by mushrooms and by hemlock. The principal external use of ether is to produce cold by its speedy evaporation. Dropped on the forehead, or applied by means of a piece of thin muslin, ether diminishes vascular excitement by the degree of cold occasioned by its rapid volatilization, and is exceedingly efficacious in headache and inflammatory conditions of the brain. In burns and scalds it may be employed as a refrigerant. If its evaporation be stopped or checked, as by covering it with a compress, it acts as a local irritant, causing rubefaction; and if the application is long continued, vesication ensues. It is used with friction as a local stimulant.—Pereira.

Adulteration.—The ether of commerce is generally unsophisticated, but it is, nevertheless, found much less pure or strong than it should be. The chief adulteration to which ether is liable is by an admixture of alcohol, in which it is soluble in all proportions. The presence of spirit of wine in ether, however, is very easily recognized by pouring a certain quantity of the suspected liquid into a graduated tube, and adding a small quantity of water, which, dissolving the alcohol, produces a much more considerable diminution of volume if the ether contain that body, than when it is pure; of course, the mixture should be shaken. It should be recollected that 10 parts of water dissolve 1 of ether, and consequently that a diminution in that proportion will always take place, even with pure ether, for which an allowance must be made.—Normandy.

Sometimes ether also contains water, which is the case with what is termed *washed ether;* and if ether has been long prepared, it is often slightly acid, and leaves a peculiar odour when rubbed upon the hand. In order to procure from it perfectly *pure ether*, it must be well shaken in a close vessel with about twice its bulk of water, and allowed to separate upon the surface of the mixture; it is then poured off, and a sufficient quantity of well-burned lime added to it, whereby the water which it had acquired by the agitation is abstracted; the mixed ether and lime are then distilled, care being taken to prevent all escape of vapour, and to keep the condensing receivers cold; the first that distils over may be regarded as *pure ether*, free from alcohol and water. —BRANDE.

METHYL ETHER.—This compound, which is perfectly analogous to ordinary ether, is *methyl oxide*, $(CH_3)_2O$, and is prepared from methyl alcohol, $CH_3.OH$, by the action of sulphuric acid in a manner somewhat similar to that which has been already described. DUMAS and PELIGOT prepared it by heating 1 part of wood spirit with 4 of sulphuric acid, but ERLEMNEYER and KRIECHBAUMER, who have recently examined the reaction, find the proportion of acid to be much too large, a yield of only 27 per cent. of the ether being obtained. The best process is to heat a mixture of 13 parts of methyl alcohol, or wood spirit, with 20 of sulphuric acid gradually to 140° C. (284° Fahr.) in a flask furnished with a return condenser. The action commences at 110° C. (230° Fahr.), and it is only necessary to pass the gas through milk of lime, or a solution of caustic soda, to remove sulphurous anhydride, in order to have it pure. By the application of a powerful freezing mixture it may be condensed to a thin colourless liquid, boiling at — 20° C. (— 14° Fahr.). Concentrated sulphuric acid absorbs about six hundred times its volume of the gas, but on dropping the solution into water the ether is again liberated in the gaseous state. It has been proposed to employ this ether, instead of ordinary ether, in a modified form of ice machine.

CHLORIDE OF ETHYL, OR HYDROCHLORIC ETHER.—This compound, called "sweet dulcified spirit of salt" by the older chemists, was supposed by them to be endowed with peculiar solvent powers in regard to the salt of gold. It may be prepared in various ways, but the most usual method is to distil a mixture of sulphuric acid and alcohol with common salt, or to heat a saturated solution of hydrochloric acid in alcohol. The proportions for the first process are 1 part of highly rectified alcohol and 1 part of sulphuric acid to 2 of common salt. The acid and alcohol are first mixed, and when the liquid is cold it is poured on the salt in a retort, and the whole gently heated. At first hydrochloric acid comes off in abundance, but after a time it is accompanied by a gas which is not absorbed by water, but which is readily condensed by a freezing mixture of ice and salt to a limpid colourless liquid; this is the chloride of ethyl, which merely requires drying and redistilling to be quite pure. For the second process mentioned above, alcohol contained in a flask, surrounded with cold water, is saturated with dry hydrochloric acid gas. As soon as the gas passes through the liquid without being absorbed, the current is stopped, and the flask connected by means of a cork and bent tube with two WOULFE's bottles, the first of which contains warm water to absorb the hydrochloric acid, and the second is surrounded by a freezing mixture. On applying heat to the flask, hydrochloric acid at first comes off in torrents, but is absorbed by the water in the first bottle; after a time it is accompanied by chloride of ethyl, which passes on to the second bottle, and is there condensed. It may be prepared far more conveniently, however, by passing hydrochloric acid through boiling alcohol in an apparatus so arranged that the alcohol is condensed and flows back again, whilst the chloride of ethyl passes over in the state of vapour. GROVES has pointed out that if about one third of its weight of chloride of zinc is added to the alcohol before commencing to pass the hydrochloric acid gas, the whole of the alcohol may be converted into chloride of ethyl. Its method of formation is as follows:—

$$\begin{array}{ccccccc} \text{Alcohol.} & & \text{Hydrochloric acid.} & & \text{Chloride of ethyl.} & & \text{Water.} \\ C_2H_5.OH & + & HCl & = & C_2H_5Cl & + & OH_2. \end{array}$$

Methyl Chloride, CH_3Cl, may be prepared in a similar way.

Chloride of ethyl, C_2H_5Cl, is a limpid, mobile, colourless liquid, of specific gravity 0·920, and boils at 11° C. (60° Fahr.). It has a pleasant ethereal odour and a sweetish aromatic taste. It burns readily with a smoky green-edged flame, giving off hydrochloric acid. It is only sparingly soluble in alcohol or concentrated sulphuric acid, but readily in alcohol. It dissolves sulphur, phosphorus, volatile oils, and many resins and fats.

Chloride of ethyl, diluted with alcohol, is used in medicine; it has been recommended in catarrhal affections. Chloride of ethyl is a highly diffusible stimulant like the other ethers, but is rarely employed alone, though it has been used as an antispasmodic. It is usually prepared by dissolving hydrochloric ether in an equal volume of rectified spirit. The action of this compound seems to be similar to that of nitric ether. A scruple of it thrown into the veins of a buck augmented the renal secretion. An oz. and a half injected into the jugular vein of a dog coagulated the blood, caused difficulty of breathing, and death. It has been used in dyspeptic affections connected with hepatic obstructions. In hectic fever BERENDS found its continued use beneficial.—PEREIRA.

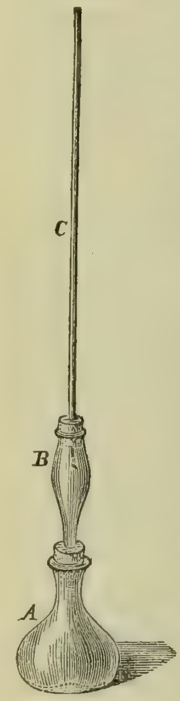
IODIDE OF ETHYL.—This compound is employed in very large quantities in the manufacture of certain of the aniline colours, such as "iodine green" and "Hofmann violet," although nitrate of ethyl is now often substituted for the iodide in the preparation of the latter.

Iodide of ethyl is always prepared by the mutual action of phosphorus and iodine on alcohol, the reaction being such that iodide of ethyl, ethyl-phosphoric acid, and water, are the sole products.

$$\begin{array}{ccccccccccc} \text{Alcohol.} & & \text{Iodine.} & & \text{Phosphorus.} & & \text{Iodide of ethyl.} & & \text{Ethyl-phosphoric acid.} & & \text{Water.} \\ 6C_2H_5.OH & + & 5I & + & P & = & 5C_2H_5I & + & C_2H_5.H_2PO_4 & + & 2OH_2. \end{array}$$

A very good method when only small quantities of the iodide are required is to place 1 part of phosphorus and 14 of alcohol in the flask, A, Fig. 9, which should be of such a capacity that it is not more than half filled by the liquid. The lower end of the adapter, B, is partially closed by means of some pieces of broken glass, so as to prevent the iodine from falling through into the flask below; 20 parts of iodine being employed, which is introduced into B in layers alternating with layers of broken glass. To the upper end of B a tube, C, about 4 feet long, is adapted to serve as a condenser, or an upright Liebig's condenser may be employed. The flask is now heated in a water bath until the alcohol boils. As it condenses and runs back through B, it gradually dissolves the iodine, which is thus introduced into the flask, where it reacts with the alcohol and phosphorus, producing iodide of ethyl. The boiling is continued until the whole of the iodine is dissolved, and the alcohol which runs back into the flask becomes colourless. When this occurs the adapter, B, is replaced by a bent tube and condenser, and the iodide of ethyl is distilled off on the water bath. After being washed once or twice with small quantities of water, dried over calcium chloride, and rectified, it is quite pure.

Fig. 9.



As iodine is but slightly soluble in alcohol, so that the reaction only takes place slowly at first, Hofmann has introduced some slight modifications in the process, which greatly facilitate the preparation of the iodide when considerable quantities are required. It is necessary, however, to have a quantity of the iodide previously prepared by the method just described. The following quantities of materials are then taken:—1000 grms. of iodide of ethyl, 1000 grms. of iodine, 700 of alcohol, and 50 of phosphorus. The phosphorus and a small portion of the alcohol are placed in a retort heated by means of a water bath, and connected with a condenser. The remainder of the alcohol, the iodine, and the iodide of ethyl are introduced into a bottle and agitated, whereby a considerable quantity of iodine is dissolved; for although not very soluble in alcohol, it is exceedingly soluble in iodide of ethyl. The dark-coloured liquid thus obtained is poured into a globe furnished with a stopcock, the neck of which passes through the tubulure of the retort, and is then allowed to run in a gentle stream into the boiling liquid in the retort. Here the iodine reacts with the phosphorus and alcohol, producing iodide of ethyl, which distils over along with that originally introduced with the iodine solution. The distillate is poured on to the undissolved iodine in the bottle, and the process continued until the whole of the iodine has been introduced into the retort. The distillate, consisting of iodide of ethyl and dilute alcohol, is then treated in a manner similar to that already described. In this method care must be taken not to allow the iodine solution to flow too rapidly into the retort, as from the neglect of this precaution explosions have occurred; the action of iodine on phosphorus being very violent, and causing the development of a large amount of heat. This source of danger may be entirely eliminated by the employment of amorphous phosphorus, but in this case the reaction does not go on so rapidly.

When amorphous phosphorus is used instead of ordinary phosphorus, it is far better to change the mode of operating. The following gives good results: 650 grms. of alcohol of at least 90 per cent., and 70 grms. of amorphous phosphorus, are introduced into a retort placed in a vessel of cold water; 1000 grms. of iodine are then added in small portions at a time, and at intervals of a few minutes, taking care to agitate between each addition. The mixture is then left for twenty-four hours and finally distilled. By this method large quantities of iodide of ethyl may be manufactured without risk of dangerous explosions.

Ethyl iodide, C_2H_5I, is colourless when pure, but quickly acquires a brown colour when exposed to light. Its specific gravity is 1·946, and it boils at 72° C. (161·6° Fahr.). It is only slightly soluble in water, but is miscible in all proportions with alcohol and ether.

Iodide of Methyl, CH_3I, closely resembles the ethyl compound. Its specific gravity is very high, being 2·23, and it boils at 43·8° C. (110·8° Fahr.). It is employed for the same purposes as iodide of ethyl, and is prepared in a similar manner, employing, however, 500 grms. of methyl alcohol or wood spirit for every 1000 grms. of iodine. As it is much more volatile than the ethyl compound, the condensing arrangements should be as complete as possible.

Acetate of Ethyl, or Acetic Ether.—The preparation and properties of this compound have already been fully described under Acetic Acid.

Acetate of Amyl, $C_5H_{11}.C_2H_3O_2$.—This ether bears the same relation to amylic alcohol, $C_5H_{11}.OH$, that acetic ether does to ordinary ethylic alcohol, $C_2H_5.OH$, and it is prepared in a very similar manner. In the rectification of raw spirit prepared from grain, or from the refuse of the beet sugar manufacture, a certain quantity of an oily substance is obtained, of a high boiling point and insoluble in water, called fusel oil. This is a mixture of alcohols from which amyl alcohol may be separated by repeated fractional distillation; it boils at 129° (264·2° Fahr.), and has a specific gravity of ·818.

The acetate may be prepared by distilling a mixture of 1 part of the purified alcohol with 1 of concentrated sulphuric acid and 2 of potassium acetate. The distillate is washed first with water, then with a dilute solution of sodium carbonate, and finally rectified, after being dried over fused calcium chloride. It may also be prepared by Fehling's method, which consists in boiling a mixture of 2 parts of amylic alcohol, 2 of glacial acetic acid, and 1 of sulphuric acid for several hours. When cold, water is added to separate the ether, which is purified in the manner above described. Pure amyl acetate is a colourless liquid, of specific gravity of ·8763 at 15° C. (59° Fahr.), and boils at 140° C. (284° Fahr.). It is insoluble in water, but miscible in all proportions with alcohol. The ether has a pleasant ethereal odour.

Butyrate of Ethyl, or Butyric Ether—*Ethyl Butyrate*, $C_2H_5.C_4H_7O_2$.—This ether is prepared from the butyric acid formed when sugar is allowed to ferment in contact with animal matter in a certain stage of putrefaction, such as rotten cheese. A very convenient process consists in mixing 2 parts of the acid with 2 of the strongest alcohol, then adding 1 part of concentrated sulphuric acid, and heating the whole to 100° C. (212° Fahr.) for an hour or two. When cold, an equal bulk of water is added, and the supernatant layer of ether removed as soon as it has separated. It is washed once or twice with water, or, better still, with a dilute solution of sodium carbonate, and rectified. It boils at 119° C. (246·2° Fahr.), and has a specific gravity of 0·902. It is only very sparingly soluble in water, but it mixes with alcohol or ether in all proportions. Butyric ether is a colourless mobile liquid possessing a powerful odour of pine apple, and in consequence is largely used for the preparation of essence of pine apple. The rum known as pine apple rum also owes its agreeable odour and flavour to the presence of this ether, which is gradually formed in the rum on keeping; the small quantity of butyric acid present in the freshly-distilled spirit slowly acting on the alcohol, and giving rise to the fragrant ether.

There is a preparation which occurs in commerce called "rum essence;" this consists in great part of butyric ether, and is made by saponifying butter, salting out the soap, and distilling this with alcohol and sulphuric acid. For this purpose 10 lbs. of the soap, and 5 of alcohol of 90 per cent., are introduced into a still and gently heated until the soap is entirely dissolved; 5 lbs. more of cold alcohol are then mixed with 10 lbs. of concentrated sulphuric acid, and the mixture added to the soap solution in the retort. A reaction, attended with the development of heat, sets in, and a spirituous liquid begins to distil. Heat is now applied to the retort, and the distillation continued until the liquid passing over begins to have a strong odour of sulphurous acid. This is removed by allowing the distillate to remain in contact with finely-powdered black oxide of manganese for a day or two, with occasional agitation, and finally distilling it off freshly-ignited magnesia. The liquid has then a very fragrant odour, and consists of an alcoholic solution of the volatile ethers of the fatty acids of the butter.

Amyl Butyrate.—$C_5H_{11}.C_4H_7O_2$.—This ether may be prepared from amyl alcohol and butyric acid in a manner precisely similar to that already described for the ethyl salt, namely, by heating a mixture of 4 parts of amyl alcohol, 3 of butyric acid, and 2 of sulphuric acid, separating the ether by the addition of water, drying, and rectifying.

Benzoic Ether, or Benzoate of Ethyl, $C_2H_5.C_7H_5O_2$.—This ether is formed by the reaction of benzoic acid with alcohol, but it is not produced by merely heating an alcoholic solution of the acid; in order to facilitate the action, it is necessary that a strong mineral acid should be present. It may be easily prepared by saturating a solution of 2 parts of benzoic acid in 4 of alcohol, with hydrochloric acid gas, and digesting the mixture for several hours in an apparatus furnished with a return condenser. Instead of passing in hydrochloric acid gas, 1 part of concentrated hydrochloric acid may be added previously to commencing the digestion. When the operation is terminated and the liquid cold, water is added so as to separate the ether. As it usually contains free benzoic acid, it must be purified by washing it with a solution of sodium carbonate, and distilling it off lead oxide. As thus prepared, it is a transparent colourless liquid, of pleasant aromatic odour, and burns with a brilliant smoky flame. It is slightly soluble in water, and miscible in all proportions with alcohol and ether. It boils at 213° C. (415·4° Fahr.), and has a specific gravity of 1·056.

Formic Ether, or Formate of Ethyl, $C_2H_3.CO_2H$.—This ether is easily prepared by distilling a metallic formate with sulphuric acid and alcohol; the proportions recommended by Döbereiner being 7 parts of sodium formate, and a mixture of 6 of alcohol with 10 of sulphuric acid. Kopp uses 8 parts of the formate, 7 of alcohol of 88 per cent., and 11 of sulphuric acid. Instead of using a formate, the formic acid may be derived from starch by the action of an oxidizing agent, such as manganese peroxide; but in this case the ether is not so pure, being contaminated with aldehyde, formed by the simultaneous oxidation of the alcohol. The ether may be prepared in this manner by pouring a mixture of 15 parts rectified spirit, 15 of water, and 30 of sulphuric acid on an intimate mixture of 10 parts of starch and 37 of binoxide of manganese in fine powder, in a capacious still, as the mass is apt to froth considerably. On applying a gentle heat, the ether distils over readily. Stinde gives the following modification of this process for manufacturing the ether on the large scale, for use in making "rum essence." Into a large iron still lined with lead, a mixture of 9 parts of starch with 29 of good, finely powdered, black oxide of manganese, of at least 85 per cent., is introduced, and on this is poured a well cooled mixture of 28 parts of sulphuric acid, 5 of water, and 15 of highly rectified alcohol. Steam is now blown into the mixture until the liquid begins to distil, when it is shut off, the heat generated by the reaction being sufficient to drive over all the ether. The first portions which come over (about half a part) consist chiefly of unaltered spirit, and should be collected apart; the remainder is the ether, which is about equal in volume to the alcohol employed, and is at once fit for use. When the distillation has almost ceased, steam may be again blown in, but what comes over must be collected apart. On adding lime to this and redistilling, an additional quantity of ether may be obtained, whilst a solution of calcium formate remains in the retort.

Formic ether may also be obtained readily by heating equal weights of dehydrated oxalic acid, alcohol, and glycerine together, in a flask furnished with an inverted condenser, until carbonic anhydride ceases to be given off, and then distilling cautiously, so as not to decompose the glycerine.

Formic ether is a mobile colourless liquid, having a strong aromatic taste, and an agreeable odour resembling that of peach kernels. It boils at 54° C. (129° Fahr.), and is lighter than water, having a specific gravity of ·9188 at 17° C. (62°·6 Fahr.) It is miscible with alcohol or ether, and is somewhat soluble in cold water, requiring about 9 parts.

Oenanthic or Pelargonic Ether, *Pelargonate of Ethyl*, $C_2H_5.C_9H_{17}O_2$.—Liebig and Pelouze obtained an ethereal oil from wine by careful rectification, and which appears to be the source of the peculiar vinous odour of Cognac. It was no doubt a mixture, but consisted chiefly of the ether of pelargonic acid, $C_9H_{18}O_2$. It may be obtained with facility from wine lees, by adding to them about half a per cent. of sulphuric acid and a considerable quantity of water, and distilling in a current of steam. A dark coloured oil floats on the surface of the distillate, which, when separated and rectified, after being washed with a solution of sodium carbonate, forms a colourless mobile liquid possessing a most powerful vinous odour, almost intoxicating if strongly inhaled. A drop or two of this added to a quart of pure spirit gives it an odour identical with that of Cognac. The ether is almost insoluble in water, but readily soluble in alcohol, even when dilute.

Pelargonic acid for the preparation of artificial "wine oil," or "grape oil," is obtained from the essential oil of garden rue (*Ruta graveolens*). This contains a methyl nonyl ketone, $CH_3.CO.C_9H_{18}$, which, when treated with oxidizing agents, gives rise to pelargonic and acetic acids. Gerhardt and Cahours prepared the acid by gently heating 1 part of the essential oil with a mixture of 1 of nitric acid and 2 of water; the action, which is violent at first, soon requires to be assisted by the external application of heat. When red fumes are no longer given off, the layer of oil is separated, washed slightly with water, and treated with a dilute solution of potash, which dissolves the greater portion, leaving a neutral oil of very acrid odour; after this has been separated, the clear alkaline solution is acidified strongly with sulphuric acid, which causes the separation of the oily acid. It merely requires to be rectified to be fit for the manufacture of the ether. Instead of oxidizing the essential oil with nitric acid, a mixture of potassium bichromate and dilute sulphuric acid may be employed. In order to prepare the ether, it is merely necessary to dissolve the acid in strong alcohol, and pass in hydrochloric acid gas as in the preparation of benzoic ether, or the alcoholic solution of pelargonic acid may be digested for some hours with concentrated hydrochloric acid. The oily layer which separates on adding water is washed with a solution of sodium carbonate to remove free acid, and rectified. Pelargonic ether boils at about 218° C. (426° Fahr.), and has a specific gravity of 0·86. There is also a solid ether or mixture of ethers occurring in commerce under the name of œnanthic ether, which is used for flavouring inferior varieties of wine, and also in the preparation of fictitious wines from beet root spirit. Its mode of manufacture is, however, a secret.

Valerianate or Valerate of Amyl, $C_5H_{11}.C_5H_9O_2$.—This ether is formed together with valeric acid and valeric aldehyde, when amylic alcohol is treated with an oxidizing mixture of potassium dichromate and dilute sulphuric acid. It may easily be prepared by pouring a mixture of 10 parts of sulphuric acid with 2 of amyl alcohol on 11 parts of finely powdered potassium dichromate and 10 of water in a retort. A considerable amount of heat is developed, and the liquid soon begins to boil, so that heat need not be applied until the action begins to slacken. The distillate consists of two layers, the lower being an aqueous solution of valerianic or valeric acid, the upper a mixture of valeric acid, valeric aldehyde, and amyl valerate. The latter may be obtained in a state pure enough for use in the manufacture of fruit essences, by agitating it well once or twice with a concentrated solution of carbonate of soda to remove the valeric acid, separating the oily layer, and distilling it. The carbonate of soda solution, which contains much valeric acid, may be added to the aqueous portion of the original distillate, the whole concentrated to a small bulk, and then decomposed by sulphuric acid. An oily layer separates, which is valeric acid; this may also be converted into amyl valerate by heating 31 parts of the acid with 22 of amyl alcohol and 25 of concentrated sulphuric acid.

Valerianic Ether, or Ethyl Valerate, $C_2H_5.C_5H_9O_2$.—This ether may be prepared from valeric acid in a manner precisely similar to that just described for amyl valerate, namely, by heating for a considerable time a mixture of 31 parts of valeric acid with 12 of highly rectified alcohol and 25 of concentrated sulphuric acid. The oily layer, which separates on the addition of water, must be agitated with a solution of sodium carbonate to remove free valeric acid, and then distilled.

Nitrite of Ethyl, or Nitrous Ether; *Ethyl Nitrite*, $C_2H_5.NO_2$.—This ether was discovered in 1681 by Kunkel, who obtained it by distilling a mixture of alcohol and nitric acid. Its formation is almost invariably due to the action of nitrous acid on alcohol, although, as in the method of preparation just noticed, the nitrous acid may be produced by the reduction of nitric acid in contact with the alcohol, and even by the alcohol itself. On this fact is founded Thénard's process, which consists in gently heating a mixture of equal parts of alcohol at 35° Baumé and of nitric acid of 32° in a capacious retort connected with three Woulffe's bottles, half filled with a saturated solution of common salt and surrounded by a refrigerating mixture. As soon as the action has commenced and the contents of the retort are in a state of brisk effervescence, the source of heat must be withdrawn; otherwise the reaction might become so violent as to cause an explosion. This risk, however, may generally be avoided by cooling the retort from time to time by the application of wet cloths, or by pouring water over it. The ether will be found on the surface of the brine in the Woulffe's bottles, and may readily be separated and purified by rectification over quick lime. The amount, however, is small, only about one-fifth of the alcohol employed being converted into the ethereal salt, the remainder being oxidized to aldehyde, acetic acid, oxalic acid, and numerous other organic compounds of purely scientific interest.

When only small quantities of the ether are required, the process given by BLACK is far better. A tall glass bottle is taken, into which 9 parts of alcohol of specific gravity ·830 are placed; 4 parts of distilled water are now introduced by means of a funnel reaching quite to the bottom of the vessel, and then in a similar manner 8 parts of concentrated nitric acid. In this way the layer of alcohol which occupies the upper portion of the column of liquid is separated from the dense nitric acid by a layer of water, so that the two can only mix slowly by diffusion. The bottle, which should not be more than three-fourths or four-fifths full, must now be loosely corked and put aside in a place where the temperature does not exceed 15° C. (60° Fahr.). A small quantity of gas is slowly evolved, and after the lapse of forty-eight to sixty hours the bottle will be found to contain only two layers, the upper consisting of the nitrous ether, whilst the lower aqueous solution is strongly acid. The ether prepared in this way, however, is never pure, always containing more or less aldehyde formed by the oxidation of the alcohol by the nitric acid.

Nitrous ether may also be prepared by distilling potassium nitrite with a mixture of alcohol and sulphuric acid. GROSOURDI recommends for this purpose, that nitrite of potassium should be made by deflagrating in a Hessian crucible a mixture of 100 parts of potassium nitrate and 12 of iron turnings; 50 parts of the product in a finely powdered state are placed in a retort with 20 of alcohol of 85 per cent., and a well-cooled mixture of 15 parts of alcohol with 24 of sulphuric acid gradually added. After allowing the whole to stand for forty-eight hours in a cool place, it is gently heated, when the nitrous ether distils over in a nearly pure state. FELDHAUS employs a somewhat similar process, differing slightly, however, in the details. He prepares the nitrite by means of lead, fusing the potassium nitrate in an iron pot, and then adding metallic lead in small portions at a time: 500 parts of the fused potassium salt, containing 68 per cent. of nitrite, are mixed in the state of powder with 1000 of alcohol of 45 per cent., and a mixture of 500 parts of sulphuric acid with an equal quantity of alcohol gradually added. After being allowed to stand some time it is distilled, when it yields 235 parts of the pure ether.

By far the best and most economical way of preparing this ether, however, is to saturate highly rectified alcohol with nitrous acid, by passing into it the gases evolved on heating a mixture of 1 part of starch with 8 of nitric acid of specific gravity 1·20; or still better, the gas given off on gently heating arsenious acid in lumps with concentrated nitric acid. As some heat is evolved during the absorption of the gas, it is necessary to keep the vessel cool which contains the alcohol. When saturated, the vessel must be tightly corked, and allowed to stand for twenty-four to thirty-six hours, when it will be found that the liquid has separated into layers, the upper of which is the ether. It is easily separated by distillation.

The ether, as obtained by any of these processes, is not pure, invariably containing traces of aldehyde, from which it is very difficult to separate it. It may be purified to a great extent, however, by washing it with a small quantity of a weak solution of sodium carbonate, drying it over calcium chloride, and redistilling. Ethylic nitrite is a very pale yellow mobile liquid, having an odour resembling that of apples. It is miscible in all proportions with alcohol and ether, but only slightly soluble in water. It is very volatile, boiling at 16·4° C. (61·5° Fahr.), according to LIEBIG, although THÉNARD gives 21° C. (69·8° Fahr.) as the boiling point. From this it will be seen that in distilling it it is necessary to cool the condensing apparatus as much as possible, the use of a refrigerating mixture being advisable in hot weather. Nitrous ether appears to decompose slowly on keeping, especially if water be present, so that occasionally the vessel containing it is burst by the pressure of the gases produced.

NITRIC ETHER, OR NITRATE OF ETHYL ($C_2H_5.NO_3$).—This ether is formed by the action of nitric acid on alcohol, and may be prepared by dropping pure well-cooled fuming nitric acid into absolute alcohol, cooled by a freezing mixture of ice and salt. On adding ice to the mixture of acid and alcohol, the ether separates and rises to the surface. It is not in this way, however, that ethyl nitrate is usually prepared, for alcohol is so readily oxidized, that under ordinary circumstances, and at ordinary temperatures, the nitric acid is readily reduced by it to nitrous acid, and the action of the nitric acid on the alcohol, *in presence of nitrous acid*, soon becomes excessively violent. If, however, nitrous acid be not present, alcohol and nitric acid may be boiled together without any oxidizing action taking place; so that if we could find a substance which will remove any trace of nitrous acid as soon as it is formed, we should have no difficulty in preparing the nitric ether. Such a substance is urea. If then we add urea to a mixture of alcohol and concentrated nitric acid we may boil the liquid with impunity, as was first observed by MILLON.

To prepare the ether, 1 part of urea is dissolved in 10 of alcohol, and a quantity of nitric acid of specific gravity 1·45 added, equal to half the volume of the alcohol; the mixture is then gradually heated, and a quantity of liquid distilled over, equal to about two-thirds of the original bulk. When the contents of the retort are cold, a fresh quantity of alcohol and of nitric acid may be poured in, and the distillation continued as before. On adding water to the two distillates, the ether separates, and may be purified by drying it over calcium chloride and redistilling. As, however, the vapour of the ether explodes violently when heated considerably above its boiling point, great care must be taken in conducting these distillations.

Pure nitric ether is miscible in all proportions with alcohol and ether, but is almost insoluble in water. It has a very sweet, somewhat nauseous taste, and burns with a white flame. It is heavier than water, having a specific gravity of 1·112 at 17° C. (62·6° Fahr.), and it boils at 86° C. (186·8° Fahr.)

Many of the ethers above described are used almost entirely in the preparation of various flavouring essences, whilst others are employed in medicine, perfumery, and in the coal-tar colour industry. Besides the extensive use of mixtures of certain ethers for improving the bouquet and flavour of poor wines, or in fraudulently imitating wines, brandy, and rum, they are employed in alcoholic solution as "fruit essences," in which the flavour and odour of various fruits are more or less successfully imitated. Although many of these ethers would undoubtedly produce deleterious effects on the human economy if taken in any large quantities, the actual amount used in the employment of the fruit essences for flavouring is so minute that all idea of danger is precluded.

Annexed are the formulæ for numerous essences given in a tabular form. It will be seen that in many cases small quantities of acid are employed; these, although not absolutely necessary, render the flavour much more like that of the fruit named. The numbers in these cases refer to a cold concentrated solution of the acid in alcohol, of specific gravity ·83:—

	Chloroform.	Ethyl Nitrate.	Aldehyde.	Ethyl Acetate.	Ethyl Formate.	Ethyl Butyrate.	Ethyl Valerate.	Ethyl Benzoate.	Ethyl Oenanthylate.	Ethyl Sebate.	Methyl Salicylate.	Amyl Alcohol.	Amyl Acetate.	Amyl Butyrate.	Amyl Valerate.	Tartaric Acid.	Oxalic Acid.	Succinic Acid.	Benzoic Acid.	Glycerine.
Pine Apple,............	1	—	1	—	—	5	—	—	—	—	—	—	—	10	—	—	—	—	—	3
Melon,................	—	—	2	—	1	4	5	—	—	10	—	—	—	—	—	—	—	—	—	3
Strawberry,............	—	1	—	5	1	5	—	—	—	—	1	—	3	2	—	—	—	—	—	2
Raspberry,............	—	1	1	5	1	1	—	1	1	1	1	—	1	1	—	5	—	1	—	4
Currant,..............	—	—	1	5	—	—	—	1	1	—	—	—	—	—	—	5	—	1	1	—
Grape,................	2	—	2	—	2	—	—	—	10	—	1	—	—	—	—	5	—	3	—	10
Apple,................	1	1	2	1	—	—	—	—	Peach Oil.	—	—	—	—	—	10	—	1	—	—	4
Pear,.................	—	—	—	5	—	—	—	—		—	—	—	10	—	—	—	—	—	1	10
Cherry,...............	—	—	—	5	—	—	—	5	1	—	—	—	—	—	—	—	—	—	1	3
Plum,.................	—	—	5	5	1	2	—	—	4	—	—	—	—	—	—	—	—	—	—	8
Apricot,..............	1	—	—	—	—	10	5	—	1	—	—	2	—	1	—	—	—	—	—	4
Peach,................	—	—	2	5	5	5	5	—	5	1	—	2	—	—	—	—	—	—	—	5

The chloroform and aldehyde can be omitted in most cases without serious detriment to the flavour, and the spirit used to dissolve the ether should have a specific gravity of ·83, and must be quite free from fusel oil. The numbers given in the table indicate the proportion of the ethers to be added to 100 of spirit by measure—fluid ounces of the ethers to 5 pints of alcohol, for instance.

EXPLOSIVES.—The attempts to replace gunpowder as a mining and blasting agent, either by modifications of that material prepared with a view to economy, or by explosive mixtures more violent in their action, have been very numerous; but few have, however, resulted in any permanent success. The substitution of the comparatively cheap sodium nitrate for saltpetre, as in the blasting powders of OXLAND, DAVY, SCHWARZ, and DE TRET, has been to some extent successful, though the hygroscopic character of that salt constitutes an insuperable difficulty to the production of any but comparatively weak powders with it. The barium nitrate has also been substituted for saltpetre in the so-called *saxifragin* powder manufactured by WYNANTS of Brussels, which was originally devised exclusively for industrial purposes, but was afterwards proposed, though without result, for use in heavy guns, on account of the comparatively gradual development of its explosive force. Charcoal has been partly or entirely replaced in powder by other artificial varieties of carbon, and also by organic substances more or less rich in hydrogen. It has even been proposed to use wood-fibre itself, instead of the carbonized product. But the chief direction which attempts to produce useful powder-surrogates has taken, is that of applying the comparatively very violent oxidizing properties of potassium chlorate. It has been proposed to substitute this salt entirely or in part for saltpetre in mixtures similar to gunpowder, and numerous preparations consisting of the chlorate more or less intimately mixed with oxidizable substances, both mineral and organic, have been experimented with, and in a few instances have received some amount of practical application. Such are modifications of the original white or German gunpowder, that is, mixtures of sugar and the prussiates of potassium with the chlorate, as made by REVELEY; or preparations consisting of mixtures of tannin, powdered nut-galls, or cream of tartar, with the oxidizing agent, as devised by HORSLEY, EHRHARDT, SHARP, and NISSER; others, such as *Teutonite*, consist of a small proportion only of the chlorate, mixed with sulphur and metallic sulphides, containing perhaps also free sulphur. Exceedingly crude mixtures of spent tan or sawdust, with saltpetre or other oxidizing salts, together with a little sulphur, have been devised apparently rather with a view to comparative safety, than to compete in effects with gunpowder (though the power of victorious competition has been claimed for some); KELLOW's powder, Pyrolithe, and Pudrolithe are preparations of this kind. Lastly, picric acid in the form of the potassium and ammonium compounds, mixed with oxidizing salts, has been made the basis of powerful explosive agents, with which experiments have been carried on in France and England.

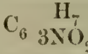
The potassium salt, when intimately mixed with the chlorate, furnishes a product which, in susceptibility to detonation and violence of action, more nearly resembles nitro-glycerine and gun-cotton than any explosive mixture composed of solid substances; it is, however, hardly applicable to practical uses on account of the great readiness with which it is exploded by friction and percussion. M. Dessignolle devoted much attention, a few years ago, to the production of safer explosive preparations, containing potassium picrate, for use in artillery and small arms. One of these, in which that salt was mixed with charcoal, saltpetre, and potassium chlorate, was experimented with at Le Bouchet on a considerable scale, with some favourable results; but the experiments were abandoned in consequence of a fearful explosion at a factory in Paris, where a large quantity of potassium picrate was stored. Much more satisfactory results have been obtained in experiments carried on by the English government with a powder proposed by Abel, and devised at about the same time by M. Barbe, composed of equivalent proportions of ammonium picrate and saltpetre. This mixture is as safely and readily prepared as gunpowder, is perfectly stable in character, and not more susceptible than the latter to explosion by friction and percussion. It has furnished satisfactory results when employed in shells and in submarine mines; the explosive force exerted by it is not greatly inferior to those of gun-cotton and dynamite.

The possibility of replacing gunpowder to any important extent, in its application to ordnance, by other explosive agents, appears at the present time as remote as it has been at any period during the history of this remarkable substance.

Gun-cotton.—Since the introduction and speedy abandonment in Austria, about twelve years ago, of gun-cotton, arranged in the form of compactly wound thread, according to Von Lenk's system, as an explosive agent for field guns, attempts to use it as a substitute for gunpowder for artillery have been limited to experiments conducted at Woolwich in 1867–68 with cannon cartridges of compressed gun-cotton. Considerable progress was made at that time towards the production of a thoroughly safe cartridge for field guns, but the experiments were suspended when much evidently remained to be accomplished before the requisite uniformity of action would have been secured. The difficulties since encountered in moderating and regulating the explosive force of gunpowder, when employed in very large charges, have shown how remote is the prospect of successfully applying explosive agents of greater violence to artillery, excepting in the smallest calibres. Partial success has on many occasions attended the employment, in small arms, of explosive agents differing considerably in character from each other, but all of them more rapidly explosive, and therefore more violent, than gunpowder. The chief advantages claimed, and more or less established for some of them over gunpowder, were the production of comparatively little or no smoke, the reduction of fouling, and increased projectile power, with the employment of comparatively small charges. Diminution of recoil has also been frequently insisted upon as an advantage, the fact being lost sight of that this result, arising out of a greater rapidity of explosion, must be attended by increased local strain upon the weapon. Many preparations containing potassium chlorate as an ingredient (such as white gunpowder, Hochstätter's and Reichen's cartridges) have been experimented with, but in no instance has the rifle-powder of the present day been successfully competed with, in regard to uniformity and accuracy of shooting at different ranges: while the comparatively great destructive effects on the weapon itself were generally more or less strikingly demonstrated during brief experience with such substances.

The first attempts to apply gun-cotton in small arms, soon after its discovery in 1846, were disastrous in their results; and the success which, long afterwards, was believed to have been achieved by Von Lenk's indefatigable labours in this direction was not confirmed by experience. Several methods of reducing the rapidity and increasing the uniformity of action of gun-cotton in small arms have since been experimented with in England. Some of these, which consisted in the uniform dilution of gun-cotton, either with ordinary cotton or with the less explosive varieties of the material, have furnished tolerably efficient cartridges for sporting purposes; but the only direction in which substantial prospect of success has hitherto attended the employment of gun-cotton in arms of precision, has been that of converting the very finely-divided substance into pellets or grains, of which the rapidity of explosion has been retarded by their uniform impregnation with small quantities of some perfectly inert material, each small particle of gun-cotton being enveloped and separated from those surrounding it by a film of non-explosive substance (*e.g.*, paraffin, stearine, or caoutchouc). Mention may here be made of a species of pyroxilin powder, known as Schultze's powder, which has found some favour for sporting purposes, and consists of finely-cut wood partially converted into nitro-cellulose, and then impregnated with oxidizing salts.

Von Lenk's persevering efforts to improve the manufacture and devise modes of application of gun-cotton, though in themselves not crowned with any permanent success, have contributed importantly to secure an unassailable position for that material as a valuable and safe explosive agent, by leading to its systematic study in England, and by the consequent development of its manufacture and discovery of its most valuable properties.

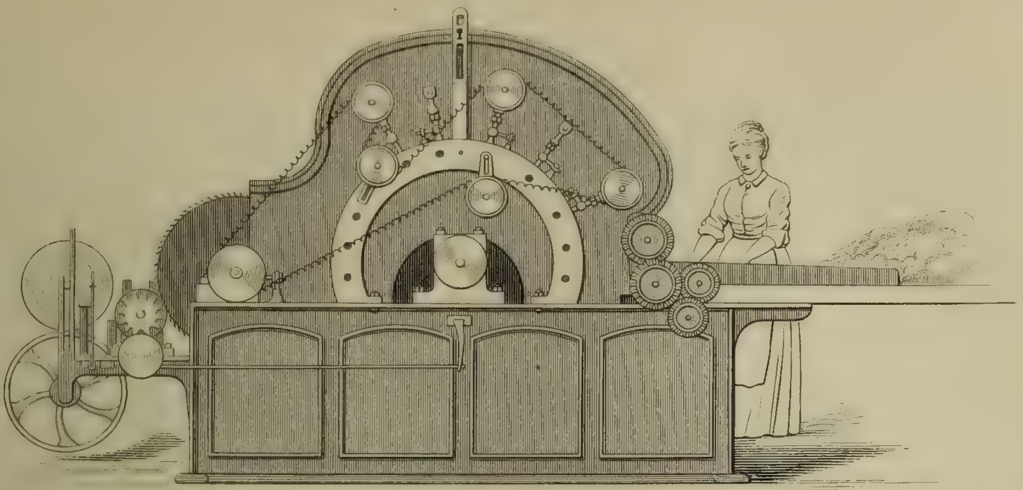
The results of Abel's analytical and synthetical researches confirmed the correctness of the formula  $C_6 \left.\begin{matrix} H_7 \\ 3NO_2 \end{matrix}\right\} O_5$, as representing the composition of the substance obtained, in a condition approaching purity, by an adherence to certain essential precautions in the production of gun-cotton, with which Von Lenk had supplemented Schönbein's original directions; they demonstrated the incorrectness of the conclusions arrived at by the most recent French investigators regarding the composition of gun-cotton, and the causes of the instability sometimes observed in that substance, and they conclusively traced its occasional liability to undergo spontaneous changes to the presence of minute quantities of foreign substances (susceptible of removal by searching purification) of comparatively unstable character, produced by the action of nitric acid upon resinous or fatty substances retained by the cotton fibre.

The practical trials made, for the English government, of gun-cotton in the different forms proposed by VON LENK for employment in artillery, shells, small arms, and mines, and ABEL's investigations on the influence of the mechanical condition of gun-cotton upon the rate of its explosion under different circumstances, proved that the control believed to have been obtained by VON LENK's system of preparation, over the explosive power of gun-cotton, was very limited; and that, while it was indispensable to the development of its full explosive force that it should be very strongly confined, even the most compact arrangement of the gun-cotton fibres, composing a cartridge to be used in a cannon or small arm, did not impede the almost instantaneous penetration of the heated gases produced by the first ignition throughout the mass, and could therefore not be at all relied upon to reduce the rapidity of explosion of gun-cotton when ignited in a nearly closed chamber, as in the bore of a gun.

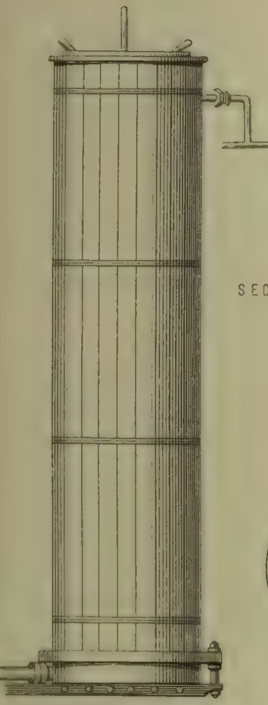
The system of manufacture devised by ABEL, which assimilated gun-cotton in its mechanical condition to gunpowder, the finely-divided material being converted by pressure into uniformly compact masses of any convenient form, led, as already pointed out, to a great advance in the safe and efficient application of the substance to small arms, and was also productive of promising results in artillery experiments, which have, however, not advanced beyond a preliminary stage. Its development into a manufacturing process resulted in very important improvements in the directions of economy, facility, and rapidity of production, and had the effect of considerably raising the standard of purity of the material. The cheapest description of cotton (machinery waste) became available as a source of gun-cotton, and the reduction of the fibre to a fine state of division greatly facilitated the application of very searching purifying processes. Moreover, the manufacturing operations became absolutely safe throughout, as even the conversion of the finished product into the compressed masses of the various forms in which it receives application is carried out with the material in a wet, and therefore perfectly uninflammable state. The minute state of division of the gun-cotton also permits of its being readily and intimately mixed with substances of a nature calculated to moderate the rapidity and violence of its explosion, or with the full proportions of oxidizing salts required for the attainment of the maximum amount of work from the carbon of the cellulose. Lastly, the conversion of gun-cotton into homogeneous highly-compressed masses has resulted, as will presently be seen, in the establishment of other most valuable and previously unsuspected properties of gun-cotton. The only, though very serious, check which the development of gun-cotton has experienced, namely, the severe explosion which occurred at the manufactory of Messrs. PRENTICE, at Stowmarket, in 1871, has been productive of beneficial results: firstly, because a very searching inquiry, instituted by government, into the cause of that explosion demonstrated that it was quite unconnected with any defect in the stability of the material, when purified according to the present system; and secondly, because the violent explosion of a considerable store of compressed gun-cotton, which in small quantities only burns rapidly, even when moderately confined, led to an investigation of the conditions attending violent explosion consequent upon the accidental ignition of gun-cotton stores.

The manufacture of compressed gun-cotton is being actively pursued at Stowmarket, and a government factory has also been in operation at the Royal Gunpowder Factory, Waltham Abbey, since the commencement of 1872. The following is a brief outline of the system of manufacture there pursued, which will be readily understood by referring to Plates I. and II:—The clippings and other waste from cotton mills (of the description in general use for cleaning machinery), after purification from oil and fatty matters by treatment with alkali, and removal of other extraneous substances, as pieces of string or rag, are passed through a machine somewhat similar to a carding engine for the purpose of opening up the material, and subsequently through a cutting machine to reduce it to a suitable condition for ready immersion into the acid. It is then rapidly and thoroughly dried by means of a powerful current of heated air in an automatic apparatus, and is weighed off while warm into metal boxes, containing 1¼ lb. each, which are closed with well-fitting lids, and left in a cold chamber for at least twenty-four hours. The contents of each box are afterwards separately immersed, by small quantities at a time, in a bath of the usual acid mixture, and allowed to remain a few minutes, the temperature being kept down by refrigerating arrangements. The gun-cotton is then removed from the acid mixture, and submitted to pressure until it retains only about ten times its weight of the liquid. In this condition it is transferred to earthenware pots, closed with well-fitting lids, in which it remains for twenty-four hours, cold water being made continually to circulate round them. When as much acid as possible has been afterwards extracted by means of a centrifugal wringing machine, the gun-cotton is carried, in small quantities at a time and with great rapidity, into a capacious tank of water by means of a large paddle wheel revolving at very high velocity, and is thus almost instantaneously drenched and rinsed. After two rinsings and very complete wringing between each, by means of the centrifugal extractors, it is allowed to soak for at least twenty-four hours in water, which is maintained at a temperature approaching 100° C. by the injection of steam. The soluble impurities of unstable

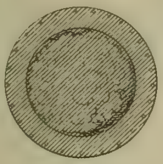
EXPLOSIVES.



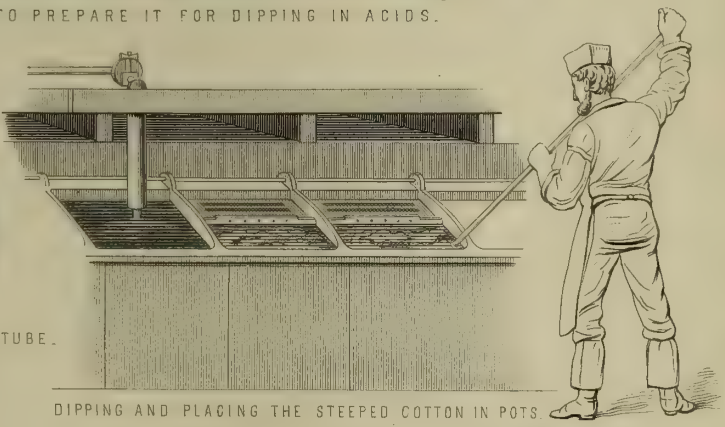
CARDING COTTON TO PREPARE IT FOR DIPPING IN ACIDS.



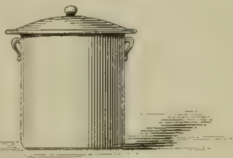
DRYING COTTON BEFORE DIPPING.



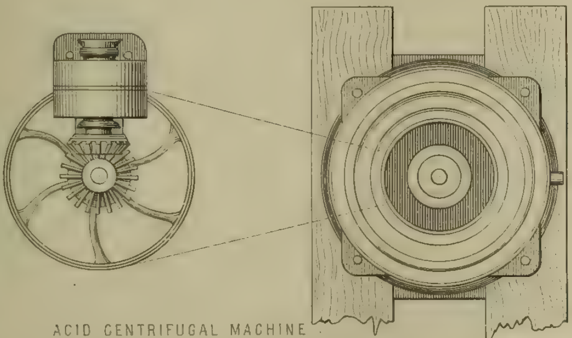
SECTION OF DRYING TUBE.



DIPPING AND PLACING THE STEEPED COTTON IN POTS.

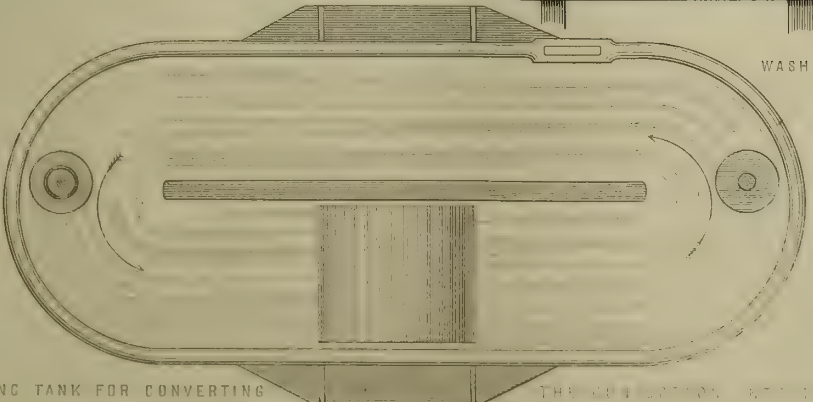


POT FOR HOLDING GUN COTTON AFTER BEING DIPPED.



ACID CENTRIFUGAL MACHINE FOR REMOVING THE LARGE EXCESS OF ACID USED IN DIPPING PROCESS.

WASHING THE GUN COTTON



BEATING TANK FOR CONVERTING THE GUN COTTON INTO PULP.

J. B. LIPPINCOTT & CO. PHILADELPHIA.

character, produced by the action of the acid upon small quantities of resinous and fatty substances which existed in the fibre, are very effectually extracted by this treatment, and the gun-cotton, after a further rinsing, is then transferred to a beating or pulping engine, of the kind ordinarily used in preparing paper-pulp. When reduced to a sufficiently fine state of division, it passes to a large washing machine (similar in construction to the so-called poaching engine of a paper work). Here the water in which the gun-cotton has been pulped is first drained off, and the pulp is very thoroughly washed by being continuously agitated together with a very large volume of water for several hours, until, in fact, samples collected at intervals satisfactorily pass a very delicate heat test for purity. This final washing process also secures very considerable uniformity in the explosive power of the finished product, as 10 cwts. of gun-cotton are washed in one operation, and the products of many hundred distinct converting operations are thus thoroughly mixed together. When the purification is complete, the finely-divided gun-cotton is intimately mixed with about 2 per cent. of alkaline carbonate, and is then converted by means of powerful hydraulic presses into compact cylinders, slabs, or pellets, the density of which is about equal to that of water. When removed from the moulds these masses still contain from 12 to 15 per cent. of water, and may be held in a flame without igniting. At this stage fuze holes are bored into them by drilling machines, or the slabs are cut to different sizes by means of band saws without any danger of ignition by friction. Before being stored they are allowed to soak in water a few minutes, so as to absorb about 25 per cent., and in this wet and absolutely uninflammable condition they are packed into wooden cases with well-fitting lids, and lined with a waterproof preparation of gutta-percha and pitch.

Gun-cotton may be preserved either immersed in water or saturated with that liquid for any period without change, and the absolute safety of the above simple method of storage has been established by experiments on a large scale. Two strong brick buildings, each containing 20 cwts. of moist gun-cotton, packed in the usual manner, were filled with combustible material, which was then inflamed. The contents of the building were gradually consumed, the compressed gun-cotton burning away slowly as the surfaces became sufficiently dry to be ignitable. Similar experiments conducted with buildings containing comparatively small quantities (6 cwts.) of dry gun-cotton (and of dynamite), resulted in some cases in violent explosions, some portion of the material being raised to the exploding temperature before any considerable quantity had been burned. The great advantage in point of safety of preserving gun-cotton in the wet state was thus convincingly demonstrated.

The drying of the substance, with the aid of steam, is a simple operation, which can be conducted expeditiously at the localities where it is to be employed; but the necessity for this operation has recently been much diminished, as will presently be shown.

NITRO-GLYCERINE.—In 1863, when the study of gun-cotton and the attempts to apply it were resumed in England, NOBEL made known his first attempts to apply nitro-glycerine practically. His original idea was to employ gunpowder as a vehicle for its application, and the violently explosive mixture obtained by saturating powder grains with the liquid possesses interest, as being really the type of the many nitro-glycerine preparations which have been called into existence as rivals to NOBEL'S dynamite. This first application of nitro-glycerine was, however, only partially successful, because of the uncertainty of developing the explosive power of that substance by the means of ignition ordinarily employed. The explosion of nitro-glycerine by simple application of heat can only be accomplished by so applying the source of heat, that decomposition is established in some portion of the mass, and is accelerated by the continued application of heat to that part. Chemical change then proceeds with rapidly accelerating violence, and the sudden transformation of the heated portion into gaseous products eventually results, proceeding almost instantaneously throughout the mass, so that the confinement of the substance is not necessary to develop its full explosive force. NOBEL first accomplished this result, though not with certainty, by applying what he termed *heaters* to some portion of the nitro-glycerine; but eventually he conceived the idea of applying, as the explosive agency, the heat and concussion produced by the detonation of a small quantity of fulminating preparation, strongly confined (as in a percussion cap), and closely surrounded by the explosive liquid. NOBEL'S earlier explanation of the rationale of this method of exploding nitro-glycerine was not satisfactory, but to him belongs the merit of first applying an *initiative detonation* as an exploding agency.

Explosion by Detonation.—The development of the full power of nitro-glycerine, when freely exposed to air, through the medium of a detonation, was for some time regarded as a peculiarity of that substance; but it was afterwards shown by BROWN of Woolwich that gun-cotton could be similarly detonated, and ABEL'S investigations on the subject showed that no explosive compound or *mixture* necessarily requires confinement for the development of its explosive force, the result being in all cases attainable by the application of an initiative detonation, the magnitude and *quality* of which varies with different explosive materials. This result is not ascribable to the simple operation of heat developed by the chemical change of the material used as the exploding agent, but to the remarkable power possessed by the explosion of small quantities of certain bodies (the mercury and silver fulminates) to accomplish detonation, though large quantities of other highly explosive substances are incapable of producing that result, and is *generally* due to the amount of force *suddenly* brought to bear on some small portion of the mass operated upon. The degree of facility with which the detonation of a substance will develop similar change in a neighbouring explosive substance may therefore be generally regarded as proportionate to the amount of force developed *within the shortest period of time* by that detonation, and to the resistance opposed to the mechanical operation of that force at the moment of its development, by the explosive substance operated upon. Some remarkable exceptional results, observed in these investigations, indicated, however, that the development of explosive force by means of initiative detonations is not always ascribable solely to the sudden operation of mechanical force. Thus, the detonation of *compressed* gun-cotton is accomplished by the explosion of 0·13 grm. of confined mercuric fulminate in close contact with the mass, but 25 times that quantity of the violent explosive substance, chloride of nitrogen, applied under the same conditions, are required to produce the same result. Again, the mechanical force exerted by the explosion of nitro-glycerine is fully equal to that developed by the fulminate, yet a quantity of nitro-glycerine 250 times greater than the minimum of the fulminate required to detonate compressed gun-cotton fails, when exploded in contact with the latter, to produce any other result than the complete mechanical disintegration of the mass. By these and similar results Abel was led to suggest that a synchronism of the vibrations developed by the explosion of particular substances may operate in favouring the detonation of one such substance by the initial detonation of a small quantity of another; while in the absence of such synchronism a much more powerful initiative detonation, or the application of much greater force, may be needed to effect the detonation of the material operated upon. This view has been supported by more recent experiments of Abel, as well as by those of Champion and Pellet, who have demonstrated that the explosion of certain very sensitive substances appears to be accomplished only by vibrations of a particular pitch, and that particular explosions affect certain sensitive flames, which are unaffected by others, unless the volume of the explosion is proportionately much increased.

Dynamite.—Although the ready susceptibility of nitro-glycerine to explosion by an initiative detonation led to its use as a most powerful blasting agent, by whose employment great economy in time and labour could be effected, its liquid nature gave rise to grave disadvantages and dangers in the employment and transport of the substance, which were demonstrated by the occurrence of numerous disastrous accidents, and were not obviated to any effectual degree by the adoption of special precautionary measures, such as the transport and preservation of nitro-glycerine in the form of a solution in methylic alcohol, from which it could be separated when required by the addition of water. Thus, in blasting operations, the nitro-glycerine with which a hole was charged might flow into fissures in the rock, and extend to places where its existence would not be suspected, and where it might afterwards be accidentally exploded during the boring of other holes.

The majority of the accidents which have occurred in different parts of the world during the transport of nitro-glycerine are considered to have been due to its leakage from the packages; the great susceptibility of the liquid to detonation, especially during hot weather or in tropical climates, would lead to the detonation of such portions by accidental concussion or comparatively slight blows, and disastrous explosions would thus be readily brought about.

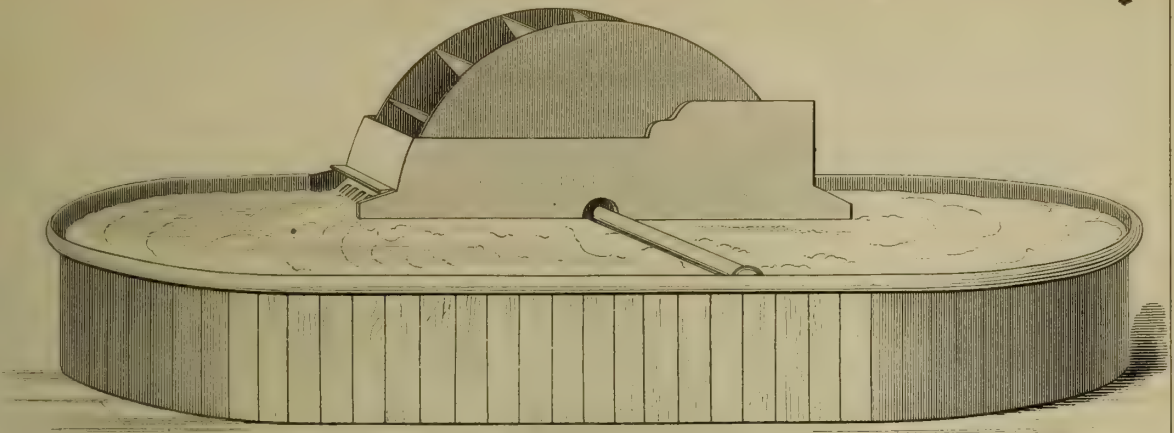
Another source of difficulty and danger in the employment of nitro-glycerine as a blasting agent, which also applies, though perhaps to a less extent, to some of its preparations, arises out of its property of solidifying at a comparatively high temperature (about 8° C.), in which condition its sensitiveness to detonation is so very greatly reduced that special means are then required to insure its explosion. Its comparative inertness in the frozen state has led, on several occasions, to a recklessly rough handling of the material, which has resulted in accidental explosions. Moreover, the necessity of thawing the substance before it can be used with the ordinary means of explosion has given rise to the incautious application of heat, and this has been a fruitful source of accident.

The obstacles to the employment of nitro-glycerine as a safe and thoroughly efficient blasting agent were, however, removed by Nobel's observation, that its ready susceptibility to explosion by an initiative detonation is not reduced, but on the contrary insured, by its admixture with solid substances, even if these are perfectly inert in character. This led Nobel to the manufacture of solid or more or less plastic preparations of nitro-glycerine, the most perfect of which (called Dynamite No. 1) consists of the porous infusorial siliceous earth known as kieselguhr, which after incineration is mixed with about three times its weight of nitro-glycerine, the mixture being converted by compression into compact cartridges.

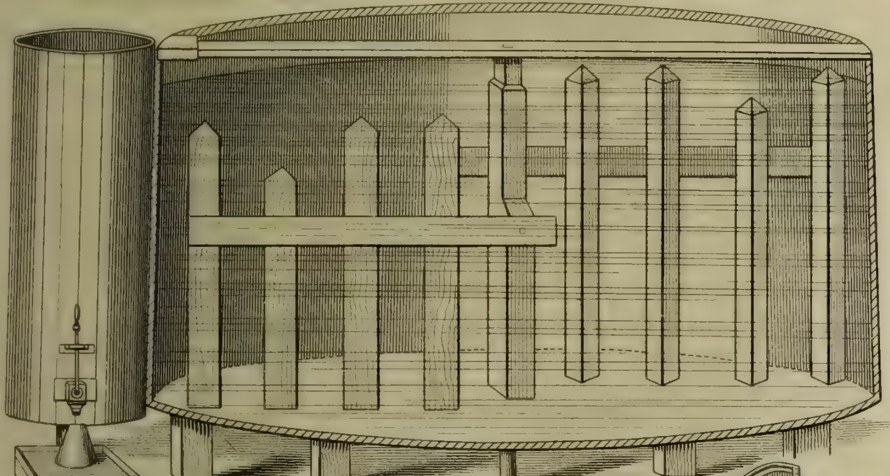
Kieselguhr appears to be one of the materials best calculated, on account of its porosity, to hold absorbed a large proportion of nitro-glycerine, even when the mixture is submitted to considerable pressure or to prolonged preservation in a warm atmosphere. Indeed, no other absorbent vehicle has yet been found quite to equal it, though during the late siege of Paris various substances, such as precipitated silica, kaolin, tripoli, precipitated alumina, sugar, and the ash of Boghead coal, were more or less successfully employed as substitutes for it.

The great efficiency and general safety of No. 1 dynamite as an explosive agent for industrial purposes has now been for some time past fully established, and it is very extensively used in all parts of the world as a valuable substitute for gunpowder in many industrial operations. Thus, two of the factories of Nobel's dynamite (at Krümmel and Zamky) produced, even in 1872, 13,400 cwts. of dynamite. There exists, besides, several factories in Germany, Italy, Sweden, France, California, and other parts of America, and an extensive factory has also been recently established, under Nobel's direction, at Ardeer, in Scotland.

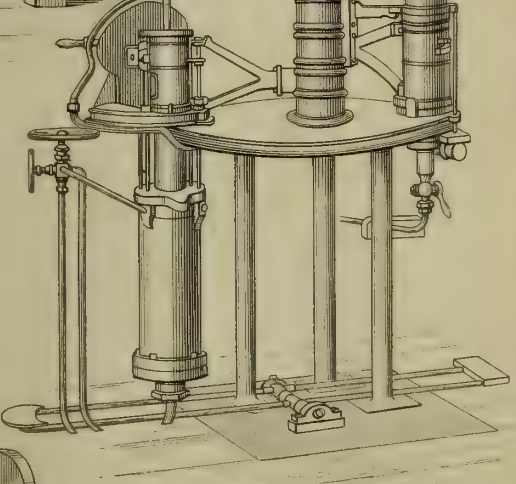
Since the idea of incorporating nitro-glycerine



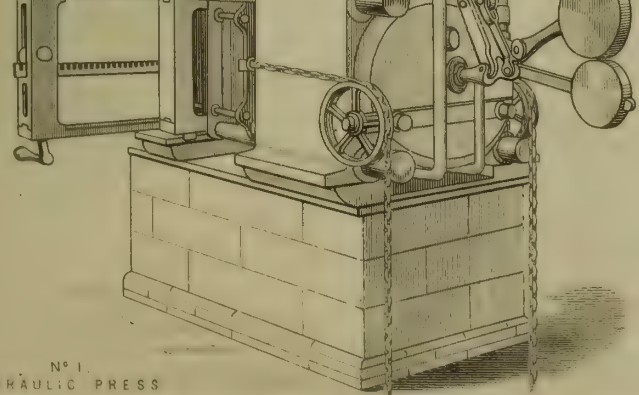
POACHER FOR WASHING THE GUN COTTON PULP.



VAT AND MIXING MACHINE



Nº 2.
HYDRAULIC PRESS.



Nº 1.
HYDRAULIC PRESS

J. B. LIPPINCOTT & CO. PHILADELPHIA.

with solid substances was first conceived by NOBEL, several preparations of that substance have been devised, in all of which the porous silica has been partly or entirely replaced by solid substances of an explosive or semi-explosive character. NOBEL himself prepares other varieties of dynamite (Nos. 2 and 3) containing much less nitro-glycerine than the original preparation, and in which mixtures of coal, charcoal, or finely divided wood, with saltpetre (or other nitrate), are constituents in various proportions, a small quantity of paraffin or ozokerit being also introduced to guard against the absorption of moisture by the mass. These preparations are designed for blasting or quarrying operations in which a comparatively mild explosive action, more nearly approaching that of ordinary gunpowder, is required. A preparation of similar character to these, but richer in nitro-glycerine, is manufactured by Messrs. KREBS & Co. of Deutz, under the name of lithofracteur, and was to some extent used by the Germans in the destruction of cannon and other operations of demolition during the Paris siege. In other preparations, such as Colonia-powder, Dualin, Glyoxiline, HORSLEY'S powder, BRAIN'S powder, and the American giant powder, the materials with which nitro-glycerine is incorporated consist entirely or partly of explosive mixtures or compounds, such as gunpowder itself, gun-cotton, or partially nitrated sawdust, or potassium chlorate mixtures. It does not appear, however, that the power of retaining absorbed a very *large* amount of nitro-glycerine which kieselguhr possesses (especially under frequent alterations of temperature, or exposure to a damp atmosphere), is shared by any of the other materials substituted for it, and this constitutes an important advantage in favour of that absorbent medium, because any tendency to exudation must obviously constitute a source of danger. The original No. 1 dynamite remains, therefore, the most generally efficient of these nitro-glycerine preparations, as well as the most powerful, because the explosive force of the other constituents which have been made to replace the inert kieselguhr is more than counterbalanced by the higher proportion of nitro-glycerine which can be converted through its agency into a suitable solid condition for safe and convenient employment.

NOBEL has not only performed invaluable service by initiating and developing the application of nitro-glycerine as a blasting and mining agent; he has also secured the distinction of founding a branch of industry which has acquired great and continually increasing importance, by being the first to elaborate a system of manufacture of nitro-glycerine. The methods pursued at the factories under NOBEL'S directions, or where his system is adopted, and those in use at some other works, differ in points of detail. Thus, some manufacturers prefer to carry on the manufacture of glycerine into the nitro-product by bringing only small quantities of that material and the acid together at one time, and then rapidly transferring the mixture to a large body of water, and this method would appear to commend itself on the score of safety; but NOBEL has adopted a method of operation, the first attempt at which demanded considerable boldness, but which, so far as present experience goes, appears not to involve special elements of danger if properly applied, and no doubt presents advantages from an economical point of view, besides promoting the attainment of uniform results. Several hundredweights of glycerine are converted into the explosive compound in a single operation, in the following manner:—A capacious cylinder, lined with stout sheet lead, is fitted with two spiral pipes or worms of lead, through which iced water circulates continuously for the purpose of keeping the contents of the vessel at as low a temperature as possible. At the commencement of the operation the latter contains the requisite quantity of the usual acid mixture, into which the glycerine is allowed to enter gradually, the two liquids being maintained in agitation by a very efficient mixing arrangement. Thermometers are fixed into the converting vessel at different depths, so that in the event of an accidental rise of temperature to a dangerous extent the contents may be immediately allowed to flow into a very capacious reservoir containing cold water. When the proper quantity (about 1500 lbs.) of glycerine has been converted, the contents of the cylinder are either allowed to run into water, which effects the separation of the nitro-glycerine from the acid, or, according to the most recent arrangements, the mixed liquids are transferred to a settling tank, so constructed as to admit of the nitro-glycerine being very completely drawn off. This tank is also provided with arrangements for immediately thoroughly mixing the two liquids, and, if necessary, for allowing them to flow off into water or into the ground, should a sudden rise of temperature accidentally occur during the process of separation. The nitro-glycerine is transferred to very capacious washing vessels (all of these receptacles consisting of thick sheet lead, suitably strengthened), where it is maintained in most intimate mixture with alkaline water by the injection of air under considerable pressure, and in a very finely divided condition: it is thus subjected to a very searching washing process, until it answers to the established test for purity. After separation from the wash-waters by filtration, and a further washing with alkaline water, the purified nitro-glycerine is converted, by simple mixing operations, into dynamite, or any of the other special preparations mentioned, and these are generally converted by hand-compressing machines into small compact cylindrical cartridges, which are inclosed in parchment paper. Notwithstanding the precautions taken against the accidental rise of temperature during the production and washing of the nitro-glycerine, more or less serious explosions during its manufacture have not been unfrequent; but its subsequent conversion into blasting preparations appears to be unattended by any liability to accidental explosions.

COMPRESSED GUN-COTTON.—*In the compressed form* gun-cotton is susceptible, like nitro-glycerine and its preparations, of explosion through the agency of an initiative detonation. Compressed gun-cotton may therefore be applied with the same facility as dynamite and analogous substances in all mining and blasting work, and in such special operations as the breaking up of large masses of iron, stone, or ice, the rapid demolition of bridges, fortifications, &c. As the highest nitrated product of cellulose (trinitro-cellulose) still demands 24·24 parts of oxygen for the *complete* conversion into carbonic acid of the carbon in 100 parts, it is evident that the most explosive gun-cotton producible must be inferior in explosive power to nitro-glycerine, which contains a very slight excess of oxygen. The system of manufacturing gun-cotton introduced by ABEL has, however, rendered the production of intimately incorporated mixtures containing the amount of oxidising agent (saltpetre, &c.) requisite for the full development of the explosive force a simple matter. The total amount of work which such products can perform is certainly greater than that of an equal weight of pure gun-cotton, and they therefore present decided advantage from an economical point of view; but their explosion is decidedly less rapid than that of gun-cotton itself or of nitro-glycerine, and hence, when great local action is required, they do not compete advantageously with those substances.

Although, however, nitro-glycerine is in its unmixed state decidedly superior in power to gun-cotton, it is not so with the actual preparations of nitro-glycerine which have proved themselves practically useful explosive agents. The most violent of these (NOBEL'S No. 1 dynamite, which consists of nitro-glycerine diluted with at least one-fourth its weight of inert material) has been stated by some experimenters to be somewhat more powerful than gun-cotton; but some careful comparative experiments made by the German engineer corps during the recent siege operations and manœuvres at Graudenz with NOBEL'S dynamite and some of ABEL'S compressed gun-cotton, manufactured at the English government works, demonstrated that the two materials were generally equal in destructive power, there being, however, indications that dynamite produced somewhat greater local or shattering effects than the gun-cotton. Many experiments carried on in England have indicated that these two materials are nearly on an equality in point of destructive power; but some strictly comparative experiments, carried out with iron plates of very uniform character, have furnished results very decidedly in favour of compressed gun-cotton. At present no other nitro-glycerine preparation has been satisfactorily proved to be fully equal to No. 1 dynamite in explosive force, for the reason that they all necessarily contain smaller proportions of nitro-glycerine (on account of the higher absorbent power of kieselguhr than of any of the solid materials by which it is partly or entirely replaced), and that the consequent reduction in total explosive force or violence of action, or both, by the removal of nitro-glycerine, is generally not compensated for and never outweighed by the explosive power of the other materials substituted for it.

The plastic condition of dynamite and similar preparations gives them an advantage over the rigid compressed gun-cotton in some blasting operations, as they may be inserted more readily into rugged and uneven bore holes, and may be made, by application of pressure, thoroughly to fill the part charged.* On the other hand, the readiness with which the nitro-glycerine preparations freeze, the slowness with which they thaw again, even in temperate atmospheres, and the necessity for using special detonators or priming cartridges for exploding them in the frozen condition, give to gun-cotton a decided advantage, as its employment in the coldest weather demands no special preparation or applications.

Serious failures in the application of dynamite to war purposes are liable to arise from the above circumstances, and by far the greater number of accidents which have occurred with dynamite have been due to the necessity of thawing the frozen material, and the great difficulty of guarding against carelessness, or of insuring the adoption of the simple and safe modes of proceeding prescribed by NOBEL.

One special advantage ascribed to nitro-glycerine preparations has consisted in the possibility of employing them in damp or wet bore-holes; but the observation that compressed gun-cotton may readily be detonated when moist or wet, by very simple means, has raised the latter almost to an equality with them in this respect, and has considerably added to the valuable properties of this substance.

ABEL has investigated the influence of dilution by solids and liquids on the susceptibility of explosive compounds, generally, to detonation, and has demonstrated that if a finely divided solid explosive body such as gun-cotton be diluted with a solid inert substance, soluble in water, and the mixture be compressed into compact masses with the aid of water, it is obtained in a condition of greater rigidity (by the crystallization of the soluble diluent), and therefore in a form more susceptible to the detonating effect of a small fulminate charge, than when the undiluted explosive by itself is very highly compressed, because the particles of the hard mass oppose greater resistance to the force developed by detonation. The reduction of activeness due to even considerable dilution is consequently almost counterbalanced by the greater rigidity of the mass; and if in the case of gun-cotton the diluent be a soluble oxidizing agent (such as saltpetre), the predisposition to chemical reaction between the two substances operates in conjunction with the effects of the crystallized salt, in imparting rigidity to the compressed mass, and the latter is consequently quite as sensitive to detonation as though it consisted only of gun-cotton. If this substance is diluted with a liquid, its sensitiveness to detonation is very greatly reduced; thus a considerably increased amount of mercuric fulminate is required to detonate gun-cotton containing 10 to 15 per cent. of water, but with sufficiently powerful detonation there is no difficulty in exploding it even if it contains 30 per cent. of water, a result which BROWN first obtained by applying the explosion of an initiative charge of dry gun-cotton to the purpose. Provided that a piece of compressed gun-cotton which is *saturated with water* is in *close contact* with a piece of air-dry gun-cotton of sufficient size, the detonation of the latter by means of the ordinary small detonating fuze will effect the explosion of the wet material with absolute certainty, and the detonation will be transmitted with great sharpness from mass to mass of similarly wet gun-cotton, if these are in contact with each other at some point, even if freely exposed to air.

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* Preparations consisting of finely-divided gun-cotton incorporated with a nitrate, and supplied either in the granulated or pulverized condition, which admits of their safe compression into the holes provided they are used in a damp condition, have recently been employed in competition with dynamite with favourable results.

The readiness and certainty with which wet gun-cotton may be applied to the various operations hitherto carried out with dry gun-cotton, or with nitro-glycerine preparations, have been demonstrated by numerous explosive experiments, and there is no question that for all military purposes a most important advantage in point of safety and simplicity has been gained, as the stores of this explosive agent may not only be kept in an absolutely uninflammable condition, but may be issued in that state for actual use. Thus, the requisite material for the rapid destruction of bridges, stockades, or fortifications, may be carried out with an army in the field without any risk of accident. Experiments which have been carried out by the Austrian artillery and engineer committees, and by the government committee on gun-cotton in England, have shown that if ammunition wagons containing packages of dynamite are fired into from military rifles, even from a distance of 1000 paces, explosion invariably results; dry compressed gun-cotton under the same conditions is frequently inflamed by the penetration of a bullet fired from a much shorter distance, but is never exploded, while wet gun-cotton in a condition ready for service cannot possibly be ignited by the same means, even at the shortest ranges.

The application of compressed gun-cotton to submarine mines has been made the subject of extensive experiment in England; and the comparative force exerted at various distances and depths of immersion, by large and small quantities of that material, confined in various ways, as well as of dynamite and other explosive agents, has been examined by means of the so-called crusher gauges, which have been applied to the measurement of the pressures exerted by exploding gunpowder. Many results of interest and importance have been obtained, of which it may be mentioned that dry compressed gun-cotton and NOBEL'S dynamite prove to be on an equality with each other, but that very decidedly greater effects were obtained by employing gun-cotton saturated with water, when *closely* but not *strongly* confined round an initiative charge of dry gun-cotton. Another important observation made in these investigations is that, provided the wet gun-cotton closely surrounds the detonator of dry gun-cotton, any small spaces between them and between the individual masses comprising a charge, may be filled with water without in any way interfering with the transmission of detonation throughout, or with the attainment of the maximum of destructive effect. Thus, results fully equal to the highest ever obtained by the explosion of gun-cotton in strong metal cases under water, have been furnished by charges which were simply held together completely by means of an ordinary fishing net.

In examining into the power of water to transmit the force developed by detonation, ABEL was led to make experiments of a novel character in hollow projectiles, which have furnished results of considerable interest, and have recently been shown, by experiments carried on at Okehampton, near Dartmoor, to possess great practical value. If only a small piece (from 0·25 to 1 oz.) of compressed gun-cotton be exploded, by means of a detonator, in the interior of a shell which is filled up completely with water, and closed, the force developed is so suddenly and uniformly transmitted in all directions that the thick hollow sphere or cylinder is broken up into seven or fourteen times the number of fragments produced by filling the shell completely with gunpowder or a more violent explosive agent (that is, from 30 to 60 times the weight of the gun-cotton used). In this simple way a hollow projectile of ordinary construction may be made to exercise the functions of a shrapnel shell. Detonations less *sudden* than those obtained with the small cylinder of compressed gun-cotton produced much inferior results, although considerably larger quantities of the explosives were used. Again, by filling a shell completely with a mixture of water and finely-divided gun-cotton, and detonating in it a charge of 1½ or 2 ozs. of dry gun-cotton, the shell being tightly closed, the resistance opposed at the *first instant*, by the strongly confined mixture of solid and liquid, to the force developed, being similar to that offered by a powerful solid body, the small particles of gun-cotton, though enveloped in and separated from each other by water, are in a position favourable to detonation, and hence a mixture absolutely harmless under all ordinary circumstances becomes a most formidable exploding agent in shells. The difficulty of employing gun-cotton in hollow projectiles, arising out of the liability of their premature explosion by the concussion to which they are subject on firing the guns (and which has been found to apply equally to dynamite), appears thus to have been satisfactorily overcome.

The transmission of detonation through air, and the circumstances which favour or impede it, have also been made a subject of investigation by ABEL, to which he was led by some interesting results on the transmission of detonation through tubes, obtained by TRAUZL with dynamite and by CHAMPION and PELLET with iodide of nitrogen. He has traced to very simple causes some remarkable differences in the apparent power of tubes of different kinds to transmit detonation, and has furnished several demonstrations of the influence of the *volume* and quality of a detonation upon the results obtained. He has also proved, by small and large experiments, that the *explosion* of a substance may be brought about as a phenomenon distinct from that of its *detonation*, in regard both to the conditions to be fulfilled for its development and the mechanical effects produced by it. Lastly, he has successfully applied a Noble's electric chronoscope to the determination of the velocity with which detonation is transmitted along a continuous mass or a row of distinct masses (either touching each other or spaced) of compressed gun-cotton, both dry and wet, of "nitrated" gun-cotton, of dynamite and nitro-glycerine. Trains or rows of the materials, varying between 24 and 50 feet in length, were employed, and the records of the rate of progress of detonation at different parts of the train were generally remarkably uniform, being mostly quite as high at the termination as at the commencement of the line of explosive material. The velocity with which detonation is transmitted along continuous rows of gun-cotton slabs or cylinders ranged from 17,000 to 20,000 feet per second, varying with the extent of contact between the individual masses employed, and with their density or compactness, but being unaffected by their form or by very considerable variations in their weight. The compressed mixtures of gun-cotton and saltpetre (nitrated gun-cotton) did not, as might have been anticipated, transmit detonation as rapidly as pure gun-cotton; but the velocity of transmission of dynamite was somewhat more rapid, ranging between 19,500 and 21,500 feet per second. It was remarked, however, that while the intervention of spaces of 0·5 inch, and even more, between the individual pieces of a row of compressed gun-cotton masses of a particular weight did not, or only very slightly, affect the rate at which detonation was transmitted, a similar spacing of masses of corresponding weight of dynamite had the effect of reducing the velocity of its detonation to less than one-third that of the velocity observed with a continuous row of cartridges. This result, and others of similar nature obtained with trains of unconfined nitro-glycerine itself, were ascribable to the physical peculiarities of the substances. Compressed gun-cotton saturated with water transmitted detonation with decidedly greater velocity than the air-dry material, a result which is in accordance with the greater sharpness or violence of action observed in practical experiments with the wet material, and is due to its increased rigidity at the moment of its exposure to the force of detonation, consequent upon the replacement of air in the pores by the comparatively incompressible liquid. In iron tubes containing small charges of gun-cotton separated by intervals of 2 and 3 feet, the detonation was transmitted from the initiative explosion to the first charge at a rate of about 12,000 feet, but after that it travelled from charge to charge only at an average rate of about 6000 feet per second.

Sprengel has recently added to our knowledge of the behaviour of explosive mixtures when subject to the influence of a detonation, by some interesting results obtained with mixtures of oxidizing agents and *liquid* combustible substances. By mixing nitric acid with such bodies in the proportions required for their complete oxidation, the products are readily detonated by the means applied to the explosion of gun-cotton, some of them, such as the nitro-benzene mixture, being very violent in their explosive action. It is very questionable, at any rate at present, whether mixtures of this kind, however violent their explosive power, are susceptible of practical application; but another method devised by Sprengel, of applying oxidizable liquids, in themselves non-explosive, as explosive agents, presents greater promise of utility. He compresses powdered potassium chlorate, or a mixture of it with a nitrate, into porous masses, which he impregnates with carbon bisulphide or mixtures of that substance with nitro-benzene. The existence of sulphur in these mixtures appears to be indispensable to the development of their detonation, unless a very powerful initiative detonation be employed.

A few special processes for obtaining preparations of nitro-cellulose, for which peculiar merits are claimed by their advocates, have been brought forward publicly in England within the last three years, after Abel's system of reducing gun-cotton to a fine state of division, and then converting it into sheets of paper, into grains or compressed masses, had been successfully developed by Messrs. Prentice of Stowmarket. By one of these, proposed by Muschamp, preparations similar to gun-cotton are manufactured from highly-purified wood fibre by the Patent Gunpowder Company. The other, devised by Punshon, consists in mixing up finely-divided gun-cotton with sugar, for the purpose of retarding its explosion (on the same principle that india-rubber, paraffin, &c., had previously been applied to this purpose), a proportion of saltpetre being added with the idea of oxidizing the sugar. The employment of saltpetre or nitrate of baryta, together with finely-divided gun-cotton, in the production of granulated or pulverulent explosive agents for mining purposes, has also been recently developed into manufacturing proportions by the Stowmarket Gun-cotton Company and the Cotton Gunpowder Company at Faversham. It is obvious that, as in the case of nitro-glycerine, gun-cotton is a fruitful source of explosive preparations, differing little in character from each other, but for each of which some special merit is likely to be claimed. Practical experience alone can establish the most effective, economical, and safe methods of applying these two valuable explosive agents to technical uses.

For particulars of the manufacture of Gunpowder, Gun-cotton, and Nitro-glycerine, see articles thus headed.

FOOD, PRESERVATION OF ANIMAL.—One of the problems which has occupied public attention for many years past is the best mode of preserving, as food for the human race, the animal substances which are in abundance in many countries, but scarce and dear in the populous and wealthy states of Europe. We were obliged to import in 1875, to supply our population, the following quantities of animal food : — Live animals — 263,698 head of cattle, 977,863 sheep and lambs, 71,988 swine; and of cured animal food—hams, 222,150 cwts.; bacon, 2,407,751 cwts.; beef, salted and fresh, 216 516 cwts.; meat, preserved or fresh, 316,733 cwts.; pork, salted or fresh, 288,392 cwts.; fish, cured or salted, 589,575 cwts.; poultry and game, alive or dead, of the value of £328,034. The aggregate value of these foreign imports of animal food was about £17,750,000 sterling, and this is quite exclusive of dairy produce (butter and cheese) and preserved fish of various kinds.

When the vast herds and flocks of cattle and sheep grazing in Russia, North and South America, Australia, and South Africa, are taken into consideration, which are in many instances only valued for their hides and tallow or wool, any effectual means of transporting the flesh to markets where it can be utilized as food becomes of high importance, not only to Great Britain, but to the various states of Europe.

For several years the Food Committee of the Society of Arts has carried on extensive inquiries and examinations as to all samples and processes of food preservation brought under their notice, and these researches, while they have not as yet led to any great and startling discovery, by which our food resources are likely to be largely and permanently increased, have still been of considerable value, as directing public attention to this most important subject, guiding future experiment, and encouraging those who have worked earnestly in endeavouring to accomplish the object in view, the general benefit of the community.

Transporting meat in a fresh or unpreserved condition to this country, is a subject which has grown in interest with the increase of our population, and the greater means they possess of late years for purchasing animal food. Notwithstanding the excellence of meat preserved by the tinning process, there has been and still is a backwardness among the labouring classes of Great Britain to receive them into general consumption. And the old problem still comes up, "How are we to preserve meat by the carcase, and deliver it in such a state in British seaports as to admit of its being kept in suitable chambers on arrival, till required and distributed over the inland districts?"

Although more than 200 patents have been taken out in this country for the preservation of food, with the exception of some specially intended for fruit and vegetables, there has been no really efficient and suitable process by which the decomposition or decay of animal substances in general could be prevented. It is true, as observed by Dr. MEDLOCK, that, taking the subject as a whole, numerous and important improvements have been made in the manufacture of ice and refrigerating machines, in the modes of pickling or salting meat, in the compression and sealing in tins of various preparations, &c., but all these contrivances, even when most successfully carried out, present some objections which are fatal to their general use; they are either injurious to the flavour or destructive to the nutritive value of the substances intended to be preserved; the processes themselves are too complicated in action or too uncertain in the results obtained; or, lastly, the cost of the preserved substance is such that it is useful only in an auxiliary sense, and is utterly inapplicable to the every-day requirements of the people at large.

Science has been at work for the last quarter of a century or more on this important question, but the commercial results are as yet but limited, for we have only arrived at the meat extracts and tinned cooked meats. The Society of Arts has for ten years kept the subject prominently before the public by the inquiries of its Food Committee, by many useful reports, and by the offer of premiums. The council of the Society state that they still look hopefully forward to the early solution of the problem in Australia or elsewhere—how to preserve meat, fresh and in carcase, during its transport to the port of shipment to the markets of this country, and to find themselves in a position to award the prize so long since offered, of £100, by Sir W. C. Trevelyan, with the Society's gold medal. The Argentine government also, by a decree in 1868, offered a premium of £1600 to the discoverer of a process of preserving fresh meat on a large scale.

Before describing in detail the various preserving processes that have been commercially carried on, or are now chiefly relied on, we shall briefly enumerate, for the guidance of those interested, the chief patents dealing with the preservation of animal food.

Passing over milk and other miscellaneous animal substances, we give a digest of the principal patents that have been taken out for the preservation of meat, passing over a few of those only provisionally protected, and which were not proceeded with.

1807, January 13, F. PLOWDEN.—Coating butcher's meat and other animal substances with concentrated extract of meat.

1810, August 25, P. DURAND.—Excluding air entirely, by inclosing in tin or other vessels, and heating them in a water bath.

1817, August 5, L. GRANHOLM.—Preserving in melted fat or hot animal fluid jelly, coating with melted suet, &c.

1819, March 23, E. MORRISON.—A modification of DURAND'S process above cited; cooking food in a steam or water bath, and keeping it perfectly air-tight.

1836, March 21, L. E. SEIGNETTE.—Preserving in brine, vinegar, or carbonic acid gas.

1844, September 19, MICHAEL FITCH.—Producing a substance to be used in preventing decomposition in provisions—pyroligneous acid, combined with salt, vinegar, or saltpetre.

1845, January 28, W. T. YULE.—Passing air through chloride of calcium to keep animal substances dry, and then inclosing them in vessels of tin.

1846, March 5, ROBERT WARRINGTON.—Coating substances to be preserved with gelatine or concentrated meat gravies, or otherwise, by dipping them in warm solutions of such substances, or dipping them in a vessel containing thin cream or plaster of Paris which, when set hard, is saturated with melted suet, wax, or stearine. The substances may be wrapped in water-proof cloth or with caoutchouc, or coated with a varnish of elastic gum. Further, preserving the substances so coated by keeping them constantly submerged in glycerine, treacle, oleine, or other matters not liable to oxidation.

1846, October 17, JOHN RYAN.—Preserving organic substances by a mixture of carbonic and hydrochloric acids, or of carbonic and acetic or pyroligneous acids.

1847, May 6, JOHN HORSLEY.—Injecting acetate of ammonia or purified pyroligneous acid into the meat, which, being eminently volatile, is given off in the act of cooking.

1851, JAMES MURDOCH.—Injecting the carcases of animals with saline liquid, made by dissolving water in certain proportion, chloride of aluminium, chloride of sodium, and nitrate of potash, alone or in conjunction with a desiccating process in a closed chamber.

1854, January 31, A. M. FATIO and F. VERDEIL.—Meat, deprived of fat and bone, is cut in slices, steamed, and sprinkled with salt, and then dried in a stove or vacuum apparatus.

1854, December 7, BLUMENTHAL and CHOLLET.—Preserving meat by drying or desiccating in small portions either in a vacuum or by the aid of heated air. By grating or otherwise reducing the meat, previously dried in small pieces, a powder is obtained, which, by being submitted to a second drying process, is completely deprived of moisture.

1855, January 6, DELABARRE and BONNET.—Coating meat, poultry, &c., with a gelatinous varnish, and exposing them to a dry current of air to desiccate perfectly.

1855, February 5, E. HARTNALL.—Preserving animal and vegetable substances by immersing them in baths of gelatine and treacle, or with a little alcohol and isinglass, and after dipping, coating them with charcoal powder.

1855, February 20, J. WOTHLY.—Dusting the meat with sugar and salt, pressing out the blood and serous matter, and moderately cooking it; wrapping joints in greased paper, and packing with melted fat in casks.

1855, February 21, G. NASMYTH.—Preserving animal or vegetable matters by discharging the atmospheric air from tin cases in a water bath and closing them.

1855, July 12, JOHN BETHELL.—Preserving meat, fat, &c., by drying out of them about 80 per cent. of the water they usually contain.

1855, September 19, R. A. BROOMAN.—Preserving animal and vegetable substances by exposing them to sulphurous acid gas, to air, and then coating them with a preserving composition composed of animal albumen dissolved at a gentle heat in a strong decoction of mallow root, with a small quantity of molasses.

1855, October 9, STEPHEN GOLDNER.—Improvements in apparatus used in cooking and preserving animal matter; the heating and arranging of metal cases for steaming meat, &c., for preserving in tins.

1855, October 27, JOSEPH HANDS.—Preserving animal substances for food by submitting them to gaseous binoxide of nitrogen, nitrous acid gas, and sulphurous acid gas, either alone or mixed.

1855, October 30, MARTIN and LIGNAC.—Preserving animal substances by drying them with a current of hot air until they lose about 50 per cent. of moisture, powerfully compressing them into boxes, filling up the interstices with concentrated liquor, soldering on the lid, and submitting them to a temperature sufficiently high to produce steam in the box.

1856, January 11, A. V. NEWTON.—A new method of curing meats and ventilating and cooling cans, vessels, &c., by circulating currents of air artificially dried by ice, or its equivalent.

1856, June 4, C. L. MARLE.—Improvements in preserving animal and vegetable substances suitable for food, by hanging pieces up in a heated chamber in an atmosphere of carbonic acid gas, then dipping them in a bath of gelatine, and lastly in a bath of tannin.

1856, August 25, GEORGE WARRINER.—Preserving alimentary substances by subjecting them to a vacuum and then covering them with glycerine, mixed with water and common salt, alcohol, or gelatine, &c.

1857, January 1, E. V. GORGES.—Expulsion of the gases from animal substances intended for food by heat, the temperature not to exceed 70° C., then drying them by simple exposure to the air or by artificial means.

1857, February 11, A. C. DANDRANT.—Preserving alimentary substances by coating them with gums or resins.

1857, July 28, P. A. BOBOEF.—Preserving animal substances by coal, peat, or wood oil, by immersion, fumigation, or spontaneous evaporation, dissolving the oil in water, or mixing the oil with inert bodies.

1857, December 16, MATTHEW SEMPLE.—Preserving the meat and other edible substances by exhausting the air, and receiving and admitting antiseptic gases or other preserving agents, and hermetically closing.

1858, February 6, GEORGE DAVIES.—Improvements in the preservation of meat and other animal substances, by using talc, either in a dry powdered state or made into a paste with salt and vinegar. When the flesh is thoroughly desiccated it may be packed in cases with dry wood sawdust. The talc is removed from the meat by washing or steeping.

1861, August 20, R. A. BROOMAN.—An improvement in preserving meat and other animal substances, by first subjecting them to the action of steam or hot air for a sufficient time to coagulate the albuminous portions on the surface; and, secondly, by immersing the meat after the above treatment in an astringent or tannin solution. The meat is then plunged into a solution of gluten and sugar of lime, or alkaline or acid salt, and afterwards placed in a hot-air stove at about 212° Fahr., in order to coagulate it. This operation is repeated three or four times until the meat is cased. If likely to be exposed to damp, an outer coating of varnish should be applied.

1862, December 8, WM. E. NEWTON.—Improvements in preserving animal substances by cutting them into pieces of from 1 to 2 lbs. weight, and depriving them of bone, tendons, and membranes. The fleshy parts are wiped, hung over vessels to receive any drippings, covered with a slight layer of dry pulverized nitrate of alumina; the juices dissolve the salt and flow copiously into the vessels beneath. The pieces of meat are wiped and immersed in fat, and then covered with a sheet of tinfoil; over this, in order to close the vessel hermetically, a layer of plaster, mixed with water and gelatine, is laid.

1863, August 25, ALEXANDER HETT and FRED. W. BASSETT.—Improvements in preserving animal substances used for food, by steeping them in a solution of sulphide or nitrate of potash or soda, thickened by gum or mucilage. It is then dipped into melted tallow, suet, or wax, or it can be placed in cases and casks, and the vacant spaces be filled by pouring in such substances.

1863, November 24, G. W. YAPP.—Improvements in the preservation of animal substances, by cutting the meat into pieces from 2 to 12 lbs., and placing them in metallic or other vessels impervious to air, in order to prevent the evaporation of the liquid in which it is preserved The liquid is either bouillon or thin soup, or simply plain water with the addition of anhydrous glycerine in the proportion of 1 to 3 per cent. of the liquid employed, concentrated acetic, pure hydrochloric, or other acid, and common salt in the same proportion as the preceding. The meat and the preserving liquor, placed in tins, are soldered down in the usual manner.

1864, February 4, JAMES YOUNG.—Improvements in the preservation of animal matters by the employment of the protoxide and carbonate of iron or other oxides and carbonates capable of absorbing oxygen by placing them along with the animal matter, or they may be placed in a separate air-tight vessel, which is in communication with the vessel or case containing the animal matter.

1864, April 16, WILLIAM CLARK.—Improvements in the preservation of meat by immersing it in a solution of sulphite, bisulphite, hyposulphites, and alkaline and other nitrites generally, and hermetically sealing the meat in closed cases containing the preservative liquids.

1864, April 29, JOHN M'CALL and BEVAN GEORGE SLOPER.—Improvements in preparing and preserving meat and poultry, by desiccating and rasping, or otherwise breaking them into small fibres, and mixing them with dried powdered vegetables and condiments, and subjecting them to strong pressure; the tablets or cakes are then covered with a gelatinous or other protecting coating, and when dry the food is ready for market.

1865, January 10, THOMAS BOWERMAN BELGRAVE.—Improvements in preserving meat by submitting it to the action of sulphurous acid gas in a closed chamber until it is saturated. When the meat is required to be cooked it is steeped in water for several hours. The addition of a little alkali, such as soda waste or common salt, to the water, facilitates the liberation of the sulphurous acid from the meat.

1865, November 10, THEOPHILUS REDWOOD.—Preservation of meat and concentration of its juices by coating with paraffin, stearic acid, and other similar substances. Improvements and modifications of the process are given in a subsequent patent, dated November 23.

1865, November 13, WILLIAM FOX.—Improvements in preserving meat by withdrawing oxygen, and introducing various acids having an antiseptic influence on the meat.

1865, November 16, RICHARD JONES.—Improvements in the apparatus employed for preserving tinned meats.

1865, December 20, JOHN GAMGEE.—The internal administration of certain tonic, astringent, or antiseptic agents to animals during life, in order to resist putrefaction for an indefinite period of time after death. Packing the carcase, &c., in tallow or charcoal, or filling the containing vessels with nitrogen and carbonic acid gas.

1866, January 15, F. LECOCQ.—Preserving the carcases of animals fit for food by exhausting the water therefrom and reducing them to a dry state, and subjecting them to a cold and constant or uniform low degree of temperature, but not so low as the freezing point.

1866, May 10, DONALD NICOLL.—To enable raw or uncooked meat, fish, &c., to be preserved in a fresh state and conveyed to distant places in a wholesome condition, in tanks, filled with certain preservative chemical agents.

1866, June 27, H. MEDLOCK and W. BAILEY.—Various processes and solutions described for preserving animal substances, chiefly bisulphite of lime.

1866, July 21, JOHN MORGAN.—Improvements in preserving animal substances by applying and using acetate of soda, and in sealing tins or cases containing preserved provisions, and in the apparatus employed therein.

1866, September 24 JOHN and ARTHUR GAMGEE.—The use of carbonic oxide in the process of preserving animals whose flesh is to be used as human food, whether by causing them to inhale the gas as they die, or by placing the meat in chambers or vessels containing this oxide alone, or in conjunction with other gases or vapours.

1866, November 26, N. S. SHALER.—Preserving animal substances in a chamber pervaded by an atmosphere of carbonic acid gas, at a temperature as near as may be to freezing.

1867, 9th February, W. CLARK.—Preserving animal substances wholesome and edible without material loss or change of their natural flavour.

1867, 23rd March, J. and S. GAMGEE.—Preservation of animal substances.

1867, 15th July, T. REDWOOD.—Preservation of meat and animal substances.

1868, 4th January, P. SPENCE and W. A. SMITH.

—Improvements in storing meat for transport, whereby it may be preserved, and in apparatus connected therewith.

1868, 11th January, JOHN SOMERVELL. — An improved method of obtaining and preserving alimentary substances in a highly concentrated form.

1868, 22nd February, JOHN M'CALL.—An improved mode of preserving meat.

1868, 26th March, M. B. ORR.—Arrangements and apparatus for drying and preserving animal substances.

1868, 7th April, PATRICK M'MAHON.—Destroying the decaying principle in animal substances and articles of food by means of a railroad atmospheric process.

1868, 4th May, W. ESTOR and M. TERRERO.—Means of and apparatus for preserving animal substances.

1868, 24th July, G. A. THIBIERGE.—Preserving animal and vegetable substances.

1868, 4th August, H. A. BONNEVILLE.—A new and improved process of preserving meat, and the apparatus connected therewith.

1868, 22nd August, G. H. BARBER.—Improved means of preserving meat, and in the apparatus therefor.

1868, 6th October, J. JEFFREYS.—Improvements in freezing, shipping, and preserving meat, and in the machinery and apparatus employed.

1868, 12th December, JOHN MILLWARD. — Improvements in preserving meat and animal matter, and in apparatus employed for that purpose.

1869, 13th January, C. J. GUNTHER.—A communication from BARON LIEBIG, for salting and preserving meat.

1869, 5th May, E. H. RICHMOND.—Improved apparatus and process for preserving meat and other animal food, and ingredients to be used in combination with the said apparatus.

1869, 23rd October, T. DEICHMANN.—Improvements in preserving meat.

1870, 6th April, RICHARD JONES.—Preserving of animal food and apparatus for the same.

1870, 26th September, HENRY HIGHTON.—An improved method of preserving meat and other alimentary substances.

1870, 28th September, J. J. BENGOUGH.—Improvements in preserving animal substances in air-tight vessels.

1871, May 6, T. F. HENLEY.—Removing the moisture from meat by mechanical pressure and heat combined, in order to preserve both these.

1871, October 11, W. E. GEDGE.—Steeping meat in a solution of chlorhydric acid in water, then drying and storing it.

1871, December 4, VASQUEZ and ROSENBERG.—Preserving fresh meat by placing it in casks containing a solution of acetate of lime of 6°, made slightly acid with acetic acid.

1871, December 16, R. PUNSHON.—A mode of preventing meat being over-cooked by forcing into the case, after the meat is moderately cooked, through an aperture, boiling fat, driving out the vapour, and then closing both apertures.

1872, January 29, W. G. WATHER.—Placing the refrigerating apparatus within the compartments wherein the food is stored for preservation.

1872, February 14, H. B. BARLOW. — Preserving meat by steeping for twelve hours in a solution of acetate or other salt of lime, or in lime water, and then drying.

1872, March 19, N. PRADA.—Injecting into the carcase acetic acid or an alkaline salt.

1872, March 19, R. MONTEITH.—Preserving animal substances by desiccating and operating upon them in vacuo.

1872, June 19, Dr. E. ABATE.—Improvements in preserving food by securing an uniform temperature in the holds of vessels a little below the freezing point.

1872, October 25, ALEXANDER ALISON.—Means of preserving and curing meat, various plans; packing it fresh or salted with liquid fat, and artificially drying raw meat.

1872, November 2, PETER FORBES.—Improvements in the means or apparatus for preservation of food substances, by regulating the heat, pressure, &c., in tins when cooking.

1872, November 13, F. N. TARGET.—Producing a vacuum, hermetically closing, placing a layer of charcoal mixed with antiseptic salts on a sheet of tin above the food, and filling melted lard or grease into the vessels.

1872, December 14, S. HICKSON.—Meat in a raw state, with the surface dried, is placed in closed cases and embedded with sugar.

1873, January 18, T. F. HENLEY.—Improvements in the manufacture of meat extract.

1873, February 26, METGE and VUIBERT.—A mode of preserving meat in bulk, in its fresh or cooked condition, by glazing over with a preparation of sugar and alcohol, and casing in a bed of fat, exhausting the air, and closing.

1873, July 30, a process communicated by A. F. C. REYNOSO.—Desiccating by agitating with sulphuric acid, compressing by hydraulic pressure into blocks after disintegration.

1873, July 30, W J. COLEMAN.—Preserving by various salts and acids and sugar.

1873, August 8, J. G. PETRIE.—Nearly the same as the last mentioned.

1873, November 27, Dr. C. A. LINDEMANN.—Preservation of animal substances by boric acid and its various compounds.

1874, September 5, H. BOLLITER.—Spreading a compound over the meat consisting of two-thirds common salt and one-third nitre, heating in an oven or chamber on perforated plates for about ten or fifteen minutes, at 212° Fahr., and then hermetically closing.

The several methods of preserving flesh may be conveniently classed and described under four broad heads:—

1. The simple plan of drying.
2. The use of cold.

3. The employment of chemical antiseptics.

4. The expulsion of atmospheric air by heat.

1. *The drying process* is a very good one, but can hardly be looked upon as a scientific one in connection with food preservation, though large numbers of patents have been taken out for its application. Modern science has suggested several improvements on the original crude method of drying in the sun, but no kind of desiccated meat has yet found general favour in the eyes of the public.

The process of desiccation does not answer for fat meats, as the fat will appear as oil upon the surface.

Either by the entire removal of oxygen, or the entire removal of moisture, the tendency to putrefaction is destroyed, and the food is preserved. The desiccated food may have its properties restored by immersion in salt water for one or two days.

The South American sun-dried meats, the Hamburg hung beef, and other kinds of desiccated meats, are not popular in this country. In preparing the charqui or dried meat for export in Chili, whence about 5000 cwts. are shipped, the bones and fat are removed from the flesh, which is cut into strips a quarter or three-eighths of an inch thick, and hung up in the full rays of the sun; in about eight hours it is dried as hard as a piece of glue.

It is then packed in raw hides, which shrink upon it and keep it very tight. Meat dried in this way does not putrefy, but after a time mites are found in it. In Buenos Ayres, where it is first partially salted, and afterwards dried, the fat is left and the meat becomes rancid; but with the negro population of Brazil and the West Indies (for whom it is intended), a little fat is an advantage in their stews and soups. The exports of charqui or dried beef from Buenos Ayres amounts to about 40,000 tons annually.

In the Eastern Archipelago, under the name of dendeng, the flesh and sinews of the buffalo, deer, and wild hog, similarly dried in the sun, form a considerable article for export to China and Siam.

Of the powdered, compressed, or extracted meats, much cannot be said; their applications are so extremely limited that it is out of the question to consider them in relation to the broad subject of food for the people. For travellers, invalids, children, &c., they are frequently of service in the absence of more rational food, but their cost is always triple or quadruple that of the more common but practically wholesome beef and mutton.

David Urquhart, in 1873, submitted to the Food Committee samples of meat preserved by a process of desiccation at a low temperature, by means of a vacuum.

Another process, Bancroft's desiccated beef from Queensland, imported by Messrs Orr & Honeyman of Glasgow, was highly spoken of by the Food Committee, and the preservation is perfect. It is prepared by mincing the raw meat, drying it on iron plates heated by steam below, with fanners above, 5 lbs. of meat being reduced to 1 lb. It is then ground to a powder and packed in tins.

The composition or analysis is,

Organic fibre, with abundance of nitrogen and sulphate,	90·6
Water,	7·7
Mineral ash, sulphate of potash chiefly	1·7
	100·0

It is highly nutritious, but requires a little soaking before use. It would be valuable in the preparation of soups, beef tea, potted meats, curries, and hashes. The Committee consider it likely to prove a valuable and cheap addition to the food resources of the people. Some, from a tin which had been opened upwards of two years, made into soup with vegetables, was stated to be excellent.

When submitted to the Food Committee in 1872, it was thus reported on by Dr. A. S. Taylor, F.R.S. "This sample contains all the usual constituents of dried, uncooked flesh, excepting the colouring matter of the blood. It contains 86 per cent. of dried fibrine, albumen, and gelatine, the greater part of which is fibrine. It contains from 60 to 65 per cent. less water than is usually found in fresh meat (beef). There is no appreciable amount of fat or oily matter. It contains within a small bulk all the usual constituents of nutritious animal food, and no mineral or other ingredients to affect its qualities as food. The objection to it is, that the process of preservation deprives it of that agreeable flavour of meat which stimulates appetite and creates a desire for food, no doubt owing to volatile matters lost in the desiccation process, which no art can restore. Salt would give a saline taste, but unless at the same time some such article as the Ramornie or Liebig's meat extract is used for flavouring, it would be mawkish and repulsive as food. I do not doubt that it is highly nutritious, and capable of supplying the waste of tissue like other kinds of nitrogenous animal food. It cannot be regarded as a cheap substitute for fresh meat, but under dearth or privation, when all the usual sources of animal food fail, it would undoubtedly be the means of sustaining life. Its perfectly dried state renders it as imputrescible as quill, and it might, therefore, be available as food, in a highly condensed form, on voyages or land expeditions in which provisions in some form or other must be carried."

The concentration or condensing of flesh into meat extract calls for notice, from the importance which the business has attained in Australia and South America, chiefly, however, the latter. In 1847 Liebig occupied himself with researches as to the best mode of making an extract of meat; and by his advice Giebert, an engineer of Hamburg, established a factory at Fray Bentos in Uruguay. In 1860 an Antwerp company took up the enterprise, and in 1865 it was transformed into an English company, under the title of "Liebig's Extract of Meat Company, Limited." The operations of this company are carried on on a very large scale. 900 workmen are employed, and about 402 head of cattle are slaughtered daily. The flesh is immediately cut up, after separating the bones, membranes, tendons, and fat. It is chopped up by powerful machinery, then digested in large iron boilers, each holding 12,000 lbs. of meat, and heated by steam. The fat is then separated, afterwards the albumen and fibrine. It is then carefully evaporated in vacuum pans, like those employed in sugar making. Mechanical agitators set the liquid in motion, and hasten the evaporation.

When the extract is of a sufficient consistency it is resteamed and worked to render it homogeneous, and after careful examination by the chemist of the establishment, is placed in large boxes, holding 80 to 100 lbs., and sent to Antwerp, where it is transferred into small jars for general commerce.

We have not the gross production for the last few years before us, but up to 1873 about 650,000 lbs. of extract of meat were annually imported by the company into Antwerp, the produce of about 150,000 head of cattle slaughtered.

The meat extracts, however, are but a poor substitute for the flesh itself, and far too expensive to pass into general use, even if they were really nutritious. On the average, from an ox which gives 200 lbs. of flesh only 10 lbs. of meat extract can be obtained, and from a sheep weighing 40 lbs. to 50 lbs. but 1 lb. of extract. Liebig himself remarks this mode of dealing with animals goes but a small way towards remedying the deficiency and high price of meat in the European markets; for if six establishments, operating upon 1,000,000 head of cattle and 10,000,000 of sheep, prepare annually something over 10,000,000 lbs. of this extract, this would only be a pound for every three persons in the United Kingdom, leaving nothing for other European states.

As was well observed by Payen in his jury report on preserved meats at the Paris International Exhibition of 1867—"This process of manufacture leaves in the residue the fibrine, albumen, and sulphur, the cellular tissues, the adipose, the tendons, the phosphate of lime, magnesia, and other constituents, which it is hoped may some day be utilized for food. But, moreover, in extracting the most soluble substances, saline and organic, by heat, the changes which take place are not effected without injury. A great part of the aroma is dissipated, and the colour becomes darker, whilst a slight bitterness is the result." It is also found that not more than an ounce of extract can be added to a quart of water, without greatly deepening the colour of the soup and adding to its unpleasant burnt flavour.

A substance deserving incidental mention here is Darby's fluid meat, which is said to contain more of the albumen and fibrine, representing the lean of meat, than the ordinary meat extracts.

2. *The Use of Cold.*—That meat will remain in an undecomposed condition for any length of time, if kept at a temperature under 35° Fahr., has been long known; and in Canada and Northern Europe, where six months frost prevails, animals are often buried in the snow, or otherwise subjected to a low temperature, and so left till they are required for food—two, three, or more, months after. With this data on record, it is not surprising that processes of refrigeration have had all the attention that science has been able to give them. But while various chemical and mechanical refrigerators continued to fail, other efforts of a more purely chemical character were made. One of these consisted in plunging the meat while it was still warm in a solution that would have been injurious to human health if taken by itself, but which was dissipated entirely by the heat required to cook the meat. This, however, did not answer; for although the outer parts or fringes of joints were perfectly preserved for a time, as the solution would not permeate the whole joint quickly enough, decomposition began in the centre, which soon, of course, put an end to the experiment. Then it was tried under another patent to force a similar solution into quarters and joints, by subjecting them to pressure in a strong tank; but this was a still greater failure, for it was found that the pressure of fluid around joints so closed the tubes of the flesh that only a very thin coating was cured by the chemical action induced.

The preservation of animal food products for any length of time, and their transmission through various temperatures, by means of ice and freezing mixtures, has not yet been satisfactorily solved. The advantages to the public by this plan are also considerably modified by the fact that frozen animal food, when exposed to a warm temperature, will putrefy with very great rapidity. According to Dr. Cattell, animal food, and more especially fish, is always rendered less nutritious by the freezing process, and is the cause of much ill health.

Refrigeration has had enthusiastic admirers since 1842. On the 27th January of that year the first patent appears to have been taken out by Henry Benjamin and Henry Grafton for "preserving animal and vegetable matters by freezing or cooling them;" but John Lings, three years later, seems to have carried out the idea more practically in a patent for "constructing safes, chests, or closets for the reception of victuals and other perishable articles," a low temperature being the object. A number of experimenters followed in Lings' wake. Within the last few years the idea has been revived and practically tested, in some few instances with more or less success.

The public reliance seems to rest now mainly on the freezing or cooling process for successful results. When the investigation began, some ten years ago, the quantity of ice produced per ton of coal consumed did not amount to more than 4 or 5 tons, and the displacement of cargo on shipboard was excessive; but by recent improvements in the processes of evaporation and condensation, that quantity of ice or its equivalent has been raised to 15 or 20 tons.

There are many patents for refrigerating processes; one of them is that of James Harrison, to which Tellier's appears to have some resemblance.

The most recently proposed Australian process, from which so much is expected, is to convey meat inside cylinders, and reduce the temperature by a machine on Morris' plan, constructed by Price, which ultimately condenses and rarifies a solution of ammoniacal gas. In Tellier's pro-

process, patented August 11, 1874, which we shall first describe, methylated ether is vaporized and again liquefied.

This ether is gaseous at ordinary temperature, but liquefies at 30° below zero, and distils at —21°. The liquid ether flows in a sort of tubular boiler; it vaporizes in escaping at a pressure of 1 atmosphere, and produces cold. A solution of chloride of calcium circulates in the tubes of the boiler, and is the refrigerating source. The ether volatilized passes into a condenser cooled by cold water. A pump compresses anew the volatilized ether to 7 atmospheres, liquefies it, and throws it back into the boiler. The passage from the liquid state to that of vapour and the condensation of the vapours continue indefinitely, without loss of ether, and cause cold. The solution of chloride of calcium refrigerated to 20° below zero is directed into the compartment the temperature of which it is desired to lower, then led back to the refrigerator, and so the circulation of the cold is continuous like that of ether.

M. Tellier has constructed for his experiments with pulverized coke a chamber with non-conducting wall; in this there is a wooden conduit with basins of superposed sheet-iron plates. The current of cold solution of chloride of calcium circulates in these receptacles before returning to the refrigerator; a ventilator at the same time takes the air at one extremity of the chamber and withdraws the cold solution before its return to its point of departure. In these conditions the temperature is always at zero, or 1° below.

Bray's refrigerating process has been tested in America. As the result of the first experimental trial, meat was kept in a warehouse quite sound for 153 days. Following that in actual practice, two cargoes of 200 tons each were imported into New Orleans in August, 1870, the cattle in question having been killed, transported by steamer, and retailed under an average summer heat of fully 90°. The meat is kept not only cool, but dry; in fact so much drier than ordinary meat that it is not in the least affected by its transit on arrival from Liverpool to London.

The most important experiment recorded is that of James Harrison, of Melbourne, at the International Exhibition held in that city in 1872, and fully recorded in a detailed essay by the Rev. Dr. Bleesdale, published in the Victoria reports for the Vienna Exhibition. Harrison constructed a chamber after his own plan, in which he put ice in one part and quarters of beef and mutton in other parts. The safe was then sealed by the exhibition officials, and when opened at the end of forty days, and in another case eighty-five days, the meat was found perfectly sweet; and on being cooked was declared to be equal to butcher's meat as generally supplied. But there was more than this proved; for portions of these quarters of meat were kept in a temperature of from 63° to 68° before any signs of decomposition appeared. A gold medal was awarded to Harrison by the Melbourne Exhibition commissioners. So well satisfied was Harrison with this preliminary experiment that he started, in the autumn of 1873, with a safe of meat for this country in the ship *Norfolk.* But from some defects (as it was said) in the arrangement of pipes, the ice became exhausted when the vessel was within the tropics, and this, of course, put an end to the experiment. The report of the proceedings and the result of this trial are published in the *Journal of the Society of Arts* of November 28, 1873.

It has been proved that fresh meat can be transported any distance, so long as a low temperature can be maintained by refrigeration. Professor Gamgee attempted to start in 1873 The Fresh Meat Transport Company, the principle relied on being the refrigerating process, but the project fell through. It has, however, been carried out since by some Americans, who have successfully imported several hundred tons of meat in the early part of 1876, which sold well in the Metropolitan meat market. The *modus operandi* of transport in this case is as follows: A chamber is fitted up in the hold of the steamer, and around the chamber tanks for holding ice are placed. All being duly ready the cattle are killed, and the quarters are sown tightly in coarse cotton sheets. These packages are then hung in the compartment of the vessel, just close enough together for a current of air to pass freely between them. If they touched, and there were no current of air, they would begin to decompose and turn mouldy in a very short time. An artificial current is produced by a fan, which is driven by the steam power of the vessel. Thus a cold dry air, of about 35° to 38°, is preserved throughout the voyage. The meat is not frozen, but it is kept in just the required condition to make the lean firm and the fat hard, whereby decomposition is almost completely arrested. It should be remembered, however, that such meat must be consumed within a short time of its landing, as it tends to decay much more quickly than ordinary meat when brought into a warmer atmosphere.

Thomas Mort, in conjunction with Nicolle, has patented a process of refrigeration, being an application of Faraday's discovery of the liquefaction of certain gases by pressure, and the capacity of such gases for the absorption of heat on their release from liquefaction. It has for its object the introduction of improved mechanical arrangements, whereby such gases may be employed to produce a temperature sufficiently low to secure the preservation of all articles of food. Although claiming the use of other liquefying gases, he proposes to work his apparatus by means of ammoniacal gas, which by reason of its great solubility in water, and of the quantity of heat which it absorbs in passing from the liquid to the gaseous state, and on account of its safety for use on shipboard, appears to be the most suitable agent.

The apparatus and process are thus described in the Sydney papers. The larger portion of the apparatus is to be placed between decks, the feeders and desiccators, &c., where the water flows, being on deck, and the large meat-receiver or receivers down below. The material used is the liquid ammonia of commerce; this being greatly rectified, is put into cylinders called separators, the quantity of absolute ammonia in such cylinders being indicated by glass gauges. From a small steam-boiler the steam is led by a coil which passes into a closed cylinder, called a "separator;" the object in using the steam being to heat the ammoniacal solution in the separator, and so to cause the ammonia to be volatilized, or in other words resolved into gas. The gaseous ammonia is driven off from the water, and conveyed, by a series of pipes, through a number of coils, into a bath or tank of water on the deck of the vessel. The object of this is to refrigerate the gas, condensing the aqueous vapour (by which the ammonia is accompanied), so that it may return to the separators below. This particular portion of the apparatus is termed the "desiccator." In the employment of cold water for this purpose, in the bath of the desiccator, a great economy is effected; the desired end, the "drying" of the gas, not being otherwise attainable, except by an expensive chemical process. The gas, being thus dried, is forced by the heat of the steam into an iron cylinder immersed in a bath (also on deck), and there by pressure on itself, being a non-permanent gas, it becomes liquefied. This last-named vessel is called the "liquid gas receiver." From this receiver the gas, in a liquid state, is passed by pipes into an outer compartment of the "meat receiver," a large double iron cylinder, as capacious as may be required. The meat receiver of the apparatus at the ice works is a huge affair, somewhat resembling an enormous long cask outside, and in its interior not unlike a cavern. The meat receiver is made with a double casing, so as to form a compartment intervening between the "cave" and the outer surface, its walls perfectly tight, to contain the liquefied gas supplied from the liquefied gas receiver. This vessel is to be surrounded with some good non-conducting substance, such as charcoal, felt, or gutta percha, inclosed in a wooden covering, painted or varnished to exclude all moisture. The two shells of the cylinder are eccentric to each other, so that the inner shell rests on the bottom of the outer one, leaving at the top a space of about two inches. At the ends of the meat receiver are two holes, big enough to give entrance to a man, through which the meat receiver may be conveniently emptied or loaded. These orifices are made to be fastened up with wooden covers or doors, which are fitted round their oval rims with gutta percha, and securely attached into their proper places by means of screws. Having thus furnished an idea of the general nature of the apparatus, a description of the manner in which the refrigerated gas is generated and conducted to the compartment surrounding the interior of the meat-receiver follows:—The gas having been driven out of the separator, the heated water is first forced by the heat (arising from the action of the steam supplied from the boiler) through two "coolers." From the coolers it passes on, by a pipe, into an iron cylinder called the "reabsorber," which is immersed in a water tank. The separator being now emptied, is again supplied with fresh ammoniacal solution from the "feeder" on deck, and the process is repeated. The re-absorber, now containing a weak solution, is prepared to receive the gas coming into it from the compartment round the meat-receiver. It must be understood that ammoniacal gas has so great an affinity for water that water at 60° Fahr. will take up 670 times its volume of gas. The consequence of this is that when, by opening a stopcock, admission for the gas to the water in the re-absorber is obtained, it rushes in with great violence, passing from its state of liquefaction into a gaseous form, and carries with it all the caloric or heat contained in the meat, &c., it has been surrounding. It is in this transition, when the liquid expands into a gaseous state, that the freezing, or complete refrigeraton, takes place. Only as much ammonia is required at a time as will fill one of the series of receivers. From these special details of the apparatus, there is no loss whatever of the chemical substance employed. The compartment round the meat-receiver is filled with the icy current from time to time, and emptied off by the stopcocks, until all the meat, &c., in the place is frozen with as much intensity as may be desired. The ammoniacal gas is capable of freezing 100° below zero. Beyond, at 103° below zero, however, that gas itself becomes solidified. The freezing of a compartment on board ship containing 100 tons of meat would be accomplished by Mort's apparatus at the ice works in about twelve hours. The particular apparatus we have been describing would take up about 30 tons of cargo space on board a ship. The refrigerating power attained by it is enormous, considering the small bulk of the apparatus. But Nicolle has discovered a modification which will reduce the size of the apparatus to one-third, and at the same time increase its refrigerating power ten-fold. Mort claims eight things as peculiar to his invention. First, the continuous operation of the apparatus without the use of any external force, beyond the occasional application of heat from a steam boiler; second, the mode in which he applies heat to the separator; third, the mode by which he rectifies the gases after liquefaction; fourth, the mode by which he removes the weak liquor from the separator into the re-absorber by its own pressure; fifth, the mode by which he sends up into the feeder the strong liquor from the re-absorber; sixth, the mode by which he returns the strong liquor into the separator; seventh, his arrangement of the meat-receiver; and, lastly, the arrangement he has made of what he calls the "portable meat preserver."

3. *Chemical Antiseptics.*—In ordinary practice, the salting or curing plan must of necessity rank foremost, as it has been in use for centuries, and to a moderate extent is convenient, popular, and beneficial. Salted fish is used largely in almost every clime. Salt, however, is powerless to preserve meat effectually in any but the coldest weather, unless so large a quantity is employed that substances thus treated are both unpleasant to the palate and dangerous to health.

In excess salt is also very injurious, and innocent as it is popularly believed to be, more than one case of poisoning by its use has been recorded by Dr. Christison and others. Another and a grave disadvantage attending the use of salt is, that meat loses from one quarter to nearly half of its nutritive value in the usual salting processes, and is almost entirely robbed of those mineral constituents, more particularly potash, the want of which induces scurvy and other diseases.

Dr. Marcet's plan of inclosing the meat in bladder, or some similar material, before immersing it in the brine, by no means obviates these objections, although to a certain extent an improvement upon the old method of salted meats.

Salt in large quantity adds to the insolubility of the meat, and there are no means by which the chemist can get it out again. A small quantity of salt is, however, beneficial in the preservation of animal food, as chloride of sodium, added to the other principles, tends to prevent the growth of fungi.

We import on the average 210,000 cwts. of salted beef, and 262.000 cwts. of salted pork. But what we want is not salted but fresh meat.

There are very many salts, acids, and chemical compounds used as antiseptics. The fumes of sulphurous acid are powerfully antiseptic, and many patents have been taken out for their employment, among which may be specially mentioned that of Lamy, in March, 1854. Later in the same year Bellford obtained provisional protection for the use of sulphurous acid, with about one hundredth of its volume of hydrochloric acid, the object being to prevent the sulphurous acid combining with the alkaline salts of the meat, and so giving it an unpleasant flavour. Other patents followed for the use of the acid in a gaseous form; and in the specification of Demait (1855) it was directed that the substance should be preserved by hanging it up in a chamber, and exposing it to the action of the gas. Professor Gamgee renewed this process more recently, with certain modifications. It is thus described in his patents:—The animals whose flesh is to be preserved are, where this is possible, killed by causing them to inhale carbonic oxide gas, which may be generated by the action of heat on a mixture of sulphuric and oxalic acids, or of sulphuric acid and ferrocyanide of potassium, or by any other method which yields carbonic oxide gas. The animals are bled and dressed in the usual way, and the flesh may then be sold as human food, and even if it has travelled any distance it will retain a fresh and bright appearance longer than ordinary killed meat. The flesh of animals slaughtered with the aid of carbonic oxide gas or of animals slaughtered in the usual way may further be preserved as follows:—Firstly, by being placed in a closed chamber or vessel containing carbonic oxide gas alone, or a mixture of carbonic oxide and air, or other gas or vapour, for a period varying from two to twenty-four hours, with a view to a complete action on the meat and its juices. Secondly, by simple fumigation of the entire carcase or portions of the carcase, after the action of carbonic oxide, by means of sulphurous acid gas, alone or in combination with hydrochloric acid gas.

In M. Gorge's process the meat is partially dried, and then steeped in successive waters, containing hydrochloric acid and sulphate of soda. Instead of covering the meat with the chemical solution, it may be injected, as in the patents of Long (1834), Horsley (1847), Murdoch (1851), and others. Perhaps the most valuable antiseptic yet employed is the bisulphite of lime. This is very efficacious in the temporary preservation of meat. A variety of other experiments have been made in the antiseptic line, and various have been the trials held on the results during the last four years. We have had Dr. Sacc's method of the use of acetate of soda (1871), the chloralum process, Pierre Koch's method, and those of A. Goulstone and Mr. Leowy, with many others, of which there was a hope in each instance that a valuable and practical process had been discovered. Unfortunately, however, the results have not come up to the expectations formed; and after years of most diligent chemical experiments, there has been as yet no fresh meat brought to our markets, in the way of trade, preserved by means of antiseptics other than salt.

Medlock and Bailey have adopted a process of preservation of animal food by a solution of bisulphite of lime. The proportions for the steep, when the joints are large and numerous, are as follows:—

Bisulphite of lime,..................	2 quarts.
Common salt,......................	1 pint.
Water,............................	4 gals.

The joints are to be occasionally dipped into this mixture, and in hot weather a cloth, soaked in the same solution, may be wrapped round with advantage. When the meat is required for cooking, all that is necessary is to lay it in cold water for a few minutes, and afterwards to dry it thoroughly with a cloth. On a close inspection no odour or other alteration whatever will be apparent; the lean will not be reddened, nor the fat changed to the deep yellow tint so often apparent with "hung" meat, and the texture will be as at first, firm and consistent.

By Dr. Medlock's process, to preserve meat in the carcase, it is necessary to inject the bisulphite of lime into the arteries through the aorta immediately after the animal is slaughtered and the blood expelled. In the treatment of a joint of meat, it is dipped into a solution of half bisulphite of lime, of 1·050 specific gravity, and half water.

In Morgan's process, practised to some extent in Australia, nitre, alum, and common salt are the more active agents.

Robert Caldwell, of Melbourne, has a patented process carried on with varied success by the Victoria Meat Preserving Company. The meat, in large pieces, without the bone, is subjected to the action of a solution of bisulphite of lime, and being then closely packed in casks or tanks, is surrounded with melted fat.

The various processes of coating with a thin film of some substance which is air and water proof, such as wax, paraffin, collodion, gutta-percha, &c., are inefficient, for if the protecting envelope is broken or punctured at any one point, however small, decomposition sets in immediately.

Estor's process of employing stearine causes the fatty acid to be absorbed by the meat; the preservative is bland, and probably acts mechanically, though its introduction is brought about by chemical means. It does not appear to be effectual, for of some shipped to Buenos Ayres in 1870, a part was found to be spoiled, whilst the good meat was bad in colour, and the general appearance that of smoked meat.

Dr. Redwood's process consists in the immersion of fresh meat in melted paraffin, at a temperature ranging from 220° to 240° Fahr., for a time sufficient to concentrate the juices of the meat to a certain extent, and completely to expel air; after which the meat in its condensed state is covered with an external coating of paraffin, by which air is excluded and decomposition prevented.

T. F. Henley's process simply squeezes a definite amount of juice out of the fibre, and by mechanical desiccation preserves the latter intact. The pressed meat contains 10 per cent. of alcoholic extract and salt, and 50 per cent. of fibrine and other albumenoid compounds. The meat juice contains about 15 per cent. of alcoholic extract, and 50 per cent. of albumen. Flesh in its natural state consists of about 75 parts of water and 25 parts of solids. By powerful pressure the meat is turned out in the shape of highly dried pressed beef, and desiccated beef juice.

Dr. James Dewar's process is the action of sulphurous acid, by steeping the meat in the mixture about six hours, the time requisite being about half an hour for each pound of meat. It is then subjected to a temperature not exceeding 140°, so that the albumen may be preserved simply in a desiccated state.

De la Peyrouse's process consists in packing the meat in barrels in a casing of fat, with some alkaline carbonates. Some sent and returned from Buenos Ayres in 1873 was not a success. The drawback of this process is the rancidity and tallowy condition of the fat, imparting a disagreable flavour to the meat.

Manning's process of preserving raw meat in tins in Australia is one of the many methods in which sulphurous acid is made available for preventing decomposition. The meat tested in two ways, fried and as an Irish stew, though sound was not considered satisfactory in flavour.

Thibierge's process consists in dipping the joints for five minutes into dilute sulphuric acid of the the strength of about 10 of water to 1 of acid. The meat, on being taken out, is carefully wiped and dried, and then hung up for keeping. This process fails to prevent decomposition.

Baron Fabrice of Paris has tested Shauer's process, which is secret, but it is known that the meat is dipped in a vegetable decoction of an aromatic nature, which evidently contains tannin. The meat remains in the bath, and is gradually heated to a temperature of about 100° Fahr. It is then taken out, dried, and hung up for keeping. Repeated experiments have not proved the success of the process.

4. *Heat.*—The fourth process of preserving by the expulsion of atmospheric air is effected by the application of heat to the substances to be preserved when placed in tins or other receptacles. Though there are various modifications of the process, which is that invented by Appert in 1810, and known in this country as the Aberdeen process, the main principle is the same in all.

The expulsion of atmospheric air from vessels containing the meat, by means of heat, is certainly the most successful method of preparation yet adopted. There are three processes employed, known as the ordinary Aberdeen process, the steam-retort process, and the chloride of calcium process.

In some of the systems the tins are put into a chloride of calcium bath, with a small pinhole in the top of each tin for the escape of steam, and they are kept at a temperature of about 218° outside, so as to insure 212° in the interior of the meat. After cooking in that way for about four hours the pinhole is soldered up, and the heat increased to about 265° outside, so as to get a high temperature in the centre.

The average cost of preparing about 1,000,000 lbs. of preserved boiled beef annually, at the Royal Victoria Yard, Deptford, some few years ago, was found to average about 10½*d.* to 11½*d.* per lb. The salt beef cured there cost on an average £6 15*s.* the barrel of 208 lbs., or about 7¾*d.* per lb.

The meats put up in hermetically-sealed tin canisters, either with or without the addition of salt, spices, or antiseptics, have certainly been the most important. These preparations have proved of great utility to our soldiers, sailors, and explorers, as a change from the "odious salt meats," and have exercised a marked influence upon the health, comfort, and general *physique* of those classes of our countrymen, during the last quarter of a century; but there are still drawbacks to their general utility in want of flavour and nutrition, costliness, and in many cases a very unpleasant metallic taste, derived from the containing vessel. Being prepared at a temperature considerably above the boiling point of water, they are consequently over cooked in the first instance.

In order to preserve meat for food, it is important that the original properties of the meat shall be retained as much as possible. The primary object is not to cook the meat entirely, but merely to preserve it. Dr. Taylor considers that the temperature 170°, which will fix the fluid albumen, is sufficient for preservative purposes, and the fibrine and gelatine at the same time remain unchanged. Meat exposed for any considerable length of time to a temperature of 220° or 240° must be considered as over cooked. The effect of excessive boiling or heating of meat to a high temperature has a most prejudicial effect in driving out the nutritive properties, and retaining only the indigestible muscle and insoluble fibre of the flesh.

Of late years there has been a great improvement in the meat preserved in tins received from Australia. As regards the quality of the meat, its appearance, and the retention of nutritive qualities, experts report that there has been satisfactory progress made. This process may be regarded as furnishing a very valuable aid to other kinds of food, especially where it is desirable to have as large a quantity as possible of animal matter in a small compass. This mode alone has as yet fulfilled the necessary conditions of bringing meat from a distance with fully retained meat flavour, without deterioration by addition of chemical agents. No process of the latter kind, which has as yet been tested, can be said to be thoroughly successful. Either the texture of the meat has been broken down or hardened, and the flavour destroyed or altered, and in other cases such a distinct saline or mineral taste added as to preclude the adoption of such specimens as articles of general consumption.

The imports of preserved meat from Australia have largely declined, owing to an advance of 50 per cent. in the price of sheep. In 1874 North and South America entered the field, and about 46,000 tins of 4 and 6 lbs. each were sent from the River Plate, Texas, California, &c.

The extent and value of the shipments received in England have been as follows:—

1872,........	17,601 tons,	.... £906,680
1873,........	13,061 “	 733,848
1874,........	13,270 “	 751,709
1875,........	8,587 “	 593,054

Owing to the rise in the price of sheep in Australia, the shippers of preserved mutton to London, at 7*d.* per lb., sustain a heavy loss.

Lastly, we may allude to the preservation of fish, lobsters, &c., in tins. Salmon, tunny, sardines, and many other kinds, are so preserved, and very efficiently, and are thus available in all climates and at all seasons. It is principally in the United States and the British American provinces that the extensive preserving trade in salmon, lobsters, and oysters is carried on.

The preservation of fish in oil is by no means new, but has attained of late years large proportions on the Continent, and might be carried on with great advantage in many countries. Large quantities of sprats, small pilchards, herrings, and other fish, are frequently wasted, or merely converted into manure, for want of appliances to preserve them for food. The annual value of the sardines preserved in France is estimated to be about £1,000,000 sterling, and the anchovies at £16,000 or £17,000. In the Cornish seas enough anchovies might be caught to supply the British consumption; and recently the conversion of small pilchards into sardines has been carried on by a company in Cornwall, which has been awarded the medal of the Society of Arts.

The Cornish trade in salted pilchards to Europe is considerable, as well as that in cured herrings from Scotland, and these ordinary fish preparations are too well known to need description. The Americans have commenced tinning the young of a species of herring, locally called menhaden.

FUEL.—Heat is the agent which produces a certain well-known class of sensations. The condition of heat of a body is known from certain properties, which are those of a heated body. Heat can be transferred from one body to another, by the former becoming less hot, and in this manner uniform temperature may be produced. Hence equal temperatures of two bodies may be defined by there being no tendency to a transfer of heat between them. In order to measure temperature, certain fixed temperatures must be determined upon. Those generally employed in practice are the melting point of ice and the boiling point of water at the average atmospheric pressure. Another point is the absolute zero of temperature, which may be defined as the temperature corresponding to the disappearance of gaseous elasticity; it has been fixed by reasoning, although it has never been measured.

Sources of Heat.—There are various sources of heat at the disposal of mankind. The sun is supposed to be the origin of heat, as its beams enable plants to decompose carbonic acid, and so to form a store of carbon known in various forms as fuel.

WATERSTON and Sir WILLIAM THOMSON have speculated on the heat of the sun being due to a fall of a shower of matter on it, gravitation being thus the original source of heat.

Electricity is another source of heat, and by its agency a heat has been produced so intense, as not only to fuse, but to volatilize most refractory metals.

Chemical action, or combustion, and mechanical action through friction, are other sources of heat.

Chemical action is, next to the sun's rays, the commonest and most useful source of heat, and the methods of generating it in this manner are various; but that which is best known and most frequently resorted to is combustion. By *combustion* is usually understood that change which a body undergoes on being ignited in the air, and by which light and heat are evolved, whilst the substance itself disappears. Chemically considered, however, combustion is the union of two or more elements, in which heat is disengaged, and sometimes light, though not of necessity in every instance. Thus, in numerous chemical combinations, considerable heat is evolved, unattended with luminousness. Animal or vital heat is generated by the chemical changes which the food as well as the components of the body are constantly undergoing; and the movements of the members contribute to its more rapid production.

Finally, mechanical action, either by percussion or friction, is capable of disengaging heat from bodies in large quantities. For instance, if a bar of iron be struck with a hammer, a certain amount of heat will be evolved at every stroke; and by vigorously continuing the action the bar may be made red-hot.

Friction is another mechanical means of producing or developing heat. Instances of this are familiar to engineers and workers in metal who are engaged in boring, filing, &c. By rubbing one piece of ice against another, at a temperature below 32° Fahr., FARADAY produced sufficient heat to melt both, and this took place more or less quickly according to the amount of force applied in the friction. Count RUMFORD ascertained that the heat liberated in boring a piece of cannon seven and a half inches in diameter, the instrument making thirty revolutions per minute under a pressure of 10,000 lbs., was sufficient to boil 18 lbs. of water in two hours and a half. If a bar of steel be forcibly struck against a piece of flint or other hard body, the heat will be sufficient to cause the combustion of the particles of the metal which are disengaged, and which are seen to fly off in sparks.

Expansive Action of Heat.—The effects of heat upon matter are various; but that which is most important, and which will require to be considered first, as affording a convenient measure of its intensity, is its *expansive action.* In rendering solid bodies aeriform and liquid, the action of the heat overcomes the cohesive force with which the particles were held together, and separates them to a certain distance, dependent upon the temperature.

The expansion or dilatation produced in bodies by heat is a familiar phenomenon. Very great difference exists, however, as to the extent to which divers, substances are affected by the same amount of heat. In such compounds as are perfectly gaseous no opposition is offered to the expanding power of the heat, and the result is that these dilate in a regular and uniform ratio, no matter how hot or cold they may be when the heat is communicated. It is different with solids and liquids, in which the resistance offered by the varying force of cohesion must first be overcome before any discernible repulsion of the particles succeeds. When this opposing force is great, it is evident that a much larger amount of heat will be required to distend them. Hence the difference in the rate of expansion of bodies produced by this agency.

The Thermometer.—The thermometer, or heat measurer, is constructed upon the principle of the expansion of bodies by heat. It consists, in its common form, of a glass tube terminating in a bulb containing mercury or some other fluid, which fills the bulb and part of the tube; and the rise or fall of the fluid in the tube, according as the mass of it in the bulb expands or contracts, indicates the change of temperature in the surrounding medium. This most indispensable instrument was not known previous to the sixteenth century, and at its first introduction by the Florentine academicians its indications were not very trustworthy. At first temperature was estimated by the expansion of air; but this, although in common with other aeriform fluids more regular than liquids or solids in its alteration of volume by increased or diminished temperatures, offered so much inconvenience in the wide extent of its range, besides being largely affected by the varying pressure of the atmosphere, that it was found necessary to substitute another fluid. The air thermometer is now employed as a standard for the comparison of mercurial thermometers, and is referred to in scientific statements, but owing to its large bulk it cannot be employed in the usual determination of temperature. Various liquids, such as linseed oil and spirit of wine, were tried with good effect; but for general purposes mercury was found to be the most suitable. The range between its points of solidification and ebullition is greater than that of any other known fluid; it is also a good conductor of heat, and is, consequently, rapid in its indications, and sensitive to sudden changes of temperature. It is true that it experiences, like other fluids, as will be explained afterwards, a constantly increasing rate of expansion as the temperature rises, but between the freezing and boiling points of water this irregularity is so minute as to be really of little or no moment even in very accurate investigations; indeed the slight deviation which takes place is nearly compensated by the glass, which expands in much the same proportion as mercury.

There are three scales employed for this instrument. FAHRENHEIT, whose thermometer is generally used in this country, fixed the zero of his scale at the temperature of a mixture of snow and salt, and divided the interval between this and the boiling point of water into 212 equal parts or degrees, so that on this scale water freezes at 32°, and there are 180° between its freezing and boiling points. CELSIUS, in constructing his modification of the thermometer, assumed as the zero of his scale the freezing point of water, and proceeding on the decimal principle, divided the interval between this and the boiling point into 100 equal parts, so that on this scale the point of ebullition is indicated by 100°. Hence his instrument, which is used extensively on the Continent, has been called the Centigrade. In REAUMUR'S scale, as in the Centigrade, the freezing point is the zero; but the distance between the freezing and boiling points is in REAUMUR'S divided into 80 equal parts instead of 100, so that on this scale the boiling point of water is at 80°. In each of these thermometers the degrees of temperature under the zero are indicated by the sign *minus.* Thus, —15° Fahr. indicates fifteen degrees of that scale below its zero; while the same notation on the Centigrade or Reaumur scale signifies a temperature fifteen degrees of the one or the other of these scales below the freezing point of water.

By very simple formulæ the degrees of any of these thermometers may be converted into the equivalent of the others. The same distance is divided in the three thermometers into 180° in Fahrenheit's, 80° in Reaumur's, and 100° in the Centigrade. Now, dividing by 20 it will be seen that these numbers are in the ratio of 9 : 4 : 5; or, in other words, nine degrees of Fahrenheit's scale are equivalent to four degrees Reaumur's, and five of the Centigrade. Hence, indicating the respective thermometers by the initials F., R., C., the length of a degree in each will be as follows:—

$$1^\circ \text{ F.} : 1^\circ \text{ R.} : 1^\circ \text{ C.} :: \tfrac{1}{9} : \tfrac{1}{4} : \tfrac{1}{5}.$$

But the temperature is measured by the number of divisions contained in equal portions of the stem of the respective thermometers. Now, the zero point of Fahrenheit's is 32° below freezing point. If, therefore, F.° —32, R.°, C.°, indicate the same temperature on each of the three thermometers, one has the proportion—

$$\text{F.}^\circ - 32 : \text{C}^\circ : \text{R.}^\circ :: 9 : 5 : 4;$$

whence result the following equations for converting one scale into another:—

$$\begin{aligned} 4\,(\text{F.}^\circ - 32) &= 9\ \text{R.}^\circ \\ 5\,(\text{F.}^\circ - 32) &= 9\ \text{C.}^\circ \\ 5\ \text{R.}^\circ &= 4\ \text{C.}^\circ \\ &\text{or,} \\ \tfrac{1}{9}\,(\text{F.}^\circ - 32) &= \tfrac{1}{4}\ \text{R.}^\circ = \tfrac{1}{5}\ \text{C.}^\circ \end{aligned}$$

The divisions principally used are those of Fahrenheit and the Centigrade, and the equation for passing from the indications of the Centigrade to those of Farenheit, and *vice versâ* are—

$$\begin{aligned} \text{F.}^\circ &= 32 + \tfrac{9}{5}\ \text{C.}^\circ \\ \text{C.}^\circ &= \tfrac{5}{9}\,(\text{F.}^\circ - 32) \end{aligned}$$

that is, add thirty-two to nine-fifths of the number indicated on the Centigrade, and the result is the number which would be indicated by Fahrenheit; subtract thirty-two from the number indicated by Fahrenheit, and five-ninths of the remainder is the number which would be indicated by the Centigrade.

When very low temperatures, under —40° Fahr., have to be estimated, a mercurial thermometer cannot be employed, since this metal solidifies at that point; in such cases alcohol coloured by some matter is used in the bulb of the instrument. On the other hand, mercury boils at about 600° Fahr., and, therefore, when very high temperatures are to be estimated, a different instrument, termed the pyrometer, is employed, which will be described in the sequel.

Whatever be the form of thermometer, it is evident that the indications are merely relative, and do not express the actual amount of heat which a substance contains. The use of the thermometer, therefore, is merely to indicate the sensible heat, or that which is capable of being radiated or communicated from one material to another; and for this purpose it is of most important application in various branches of the arts and manufactures.

Expansion of Solids.—The rate of expansion in solid bodies is greatly dependent on their state of aggregation; hence it will be evident that the same temperature will operate differently on different solids.

The principal experiments made on the expansion of solids are those of Laplace and Lavoisier. The trough in which the bar is placed whose expansion is to be determined is fixed between four massive standards of stone. One of the ends of the bar is firmly fixed to a cross bar securely joined to two of the uprights, the other end pushes against a bar firmly attached to an axis which rotates as the bar expands, and carries with it in its rotation a telescope, which is directed toward a distant scale. Ice is first placed in the trough and the portion of the line of sight of the telescope on the scale noted. The temperature of the bath is then raised, and the corresponding increase of length measured.

The following table exhibits the rate of expansion of a few solids when heated from 32° to 212°:—

TABLE OF EXPANSION BETWEEN 32° FAHR. AND 212° FAHR.

	Linear Expansion.	Cubic Expansion.
Gold (Paris standard), annealed,	0·0015153	0·0045459
" " unannealed,	0·0015515	0·0046545
Steel, not tempered, ...	0·0010792	0·0032376
Tempered steel reheated to 65°,	0·0012395	0·0037185
Silver obtained by cupellation,	0·0019075	0·0057225
Silver (Paris standard), ...	0·0019086	0·0057258
Copper, ...	0·0017173	0·0051519
Brass, ...	0·0018782	0·0056346
Malacca tin, ...	0·0019376	0·0058128
Falmouth tin, ...	0·0021729	0·0065187
Soft wrought iron, ...	0·0012204	0·0036612
Round iron, wire drawn, ...	0·0012350	0·0037050
English flint-glass, ...	0·0008116	0·0024348
Gold, procured by parting, ...	0·0014660	0·0043980
Platinum, ...	0·0009918	0·0029754
Lead, ...	0·0088483	0·0265449
French glass with lead, ...	0·0008715	0·0026145
Sheet zinc, ...	0·0029416	0·0088248
Forged zinc, ...	0·0031083	0·0093249

From the following reasoning the coefficient of cubical expansion may be approximately deduced from the linear expansion, and the method here explained is that by means of which the column "cubic expansion" has been calculated in the previous table. Let α represent the coefficient of linear dilatation, and α' that of cubic dilatation, or the amount of expansion per degree of the scale of temperature employed; also let L and V represent the length and volume of the substance at the temperature of melting ice. Then L $(1 + \alpha)$ and V $(1 + \alpha')$ are the length and volume of the substance at one degree on the scale above the melting point of the substance. Then as the body is assumed to expand so as to retain its similarity of form,

$$\begin{gathered} V : V\,(1 + \alpha') = L^3 : L^3\,(1 + \alpha)^3 \\ 1 : (1 + \alpha') = 1 : (1 + \alpha)^3 \\ 1 + \alpha' = (1 + \alpha)^3 = 1 + 3\alpha + 3\alpha^2 + \alpha^3 \end{gathered}$$

but since α is a very small fraction, $3\alpha^2$ and α^3 may be dispensed with, and $\alpha' = 3\alpha$, that is, the cubic dilatation is three times the linear. It must be observed, however, that the expansion is not uniform for equal increments of temperature, for all bodies tend to expand more as the heat reaches a high degree.

Most solids return to their original volume when cooled; some, however, are incapable of doing so, and are permanently elongated or enlarged every time they are subjected to the influence of a high temperature. Such is the case, more especially, with zinc and lead, the particles of which, in sliding over each other, are supposed to possess an amount of adhesive friction which prevents their contraction to the full extent they had expanded.

The expansion or contraction of bodies, occasioned by an increase or diminution of temperature, takes place with enormous force. The amount of this has been estimated by Barlow, who found that a bar of metal, of one square inch section, is elongated one ten-thousandth of its length by receiving an addition to its temperature of 16° Fahr.; to produce the same effect mechanically would require a ton weight to be suspended from it, or the application of an equivalent force. A careful attention to this subject is indispensable in the science of engineering. It has been found that within the usual range of the variation of the temperature of England throughout the year, a bar of wrought iron, ten inches long, will expand about two hundredths of an inch. Were both its extremities secured firmly to other objects, this change would exert a force, tending towards their removal, of fifty tons to the square inch; hence it is to be observed that where beams of wood are to be replaced by iron ones, care should be taken that room for occasional expansion should be allowed them, otherwise very ruinous consequences might result. From the numerous and varied uses to which iron is now applied, this is a subject of very great importance. An accurate calculation must be made, and the structure so formed as that the expansion or contraction of the metal shall not endanger its stability.

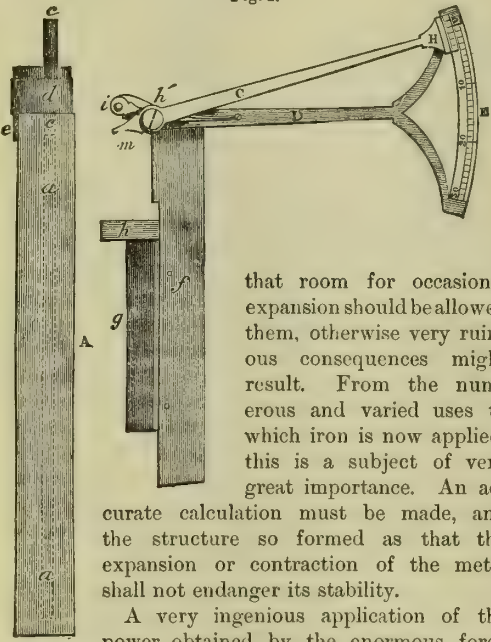


Fig. 1.

A very ingenious application of the power obtained by the enormous force of the contraction of metals was made by Molard, to secure the Museum of Arts and Manufactures in Paris, by restoring the walls, which were giving way outward owing to the weight of the roof. His method was to insert bars of iron horizontally through the building, so as to protrude a little from the walls at each side. Heat was then applied by lamps suspended over the whole length of the bars, and the metal expanded to some extent, after which iron nuts were firmly screwed on the bars at both ends, and tightened to the wall as much as possible; the heat being now removed, the metal began to contract, and in doing so it drew the nuts closer together, which had the effect of bringing the walls nearer to the perpendicular. By a repetition of the heating of the bars, and again tightening the nuts or plates, the bulges were entirely removed and the walls were restored to their vertical position. In many of the ordinary arts of life a similar advantage has been taken of the effect of heat upon bodies to render peculiar service; the wheel-wright, by heating the tire and fitting it on in an expanded state, and then allowing it to contract, insures the firmness and durability of the wheel; the cooper, in like manner, heats the hoops of his casks, &c., when fitting them in their proper place, so that when they cool they may bind the staves more firmly; and the boiler-maker uses red-hot rivets as well for facilitating their plating, as for binding the sheets of metal more tightly by their subsequent contraction on cooling.

The sudden application of heat to many bodies is productive of fracture, owing to a partial expansion of the part heated, while the part not so affected refuses to yield. This is frequently seen in glass and cast-iron plates. Indeed, the most delicate part of the glassmaker's business, as will be seen in a future article, is the annealing; or, in other words, the exposure of the goods to a gradual cooling, which renders them less liable to crack when exposed to sudden changes of temperature.

In estimating the temperature at high degrees by a mercurial thermometer, the observations made as to the rise of the metal indicate only the difference between the expansion of the glass and that of the metal, which, in ordinary cases, is supposed to be uniform; but owing to the increased expansion which the mercury experiences at a high temperature, 572° F. on the air thermometer corresponds with 586° F. on the mercurial one. The same temperature estimated by glass alone would be indicated by 667° F., thus showing that the dilatation of the glass counteracts the expansion of the fluid metal. At temperatures which liquids and gaseous bodies cannot be employed to measure, the true indication of heat, as compared with the air thermometer, is somewhat difficult to ascertain. A further obstacle stands in the way, inasmuch as the rate of expansion in metals and most solid bodies is unequal. Breguet contrived to overcome this by constructing a solid thermometer, composed of a compound ribbon of three metals—gold, platinum, and silver—rolled out very thin and coiled spirally. The upper end of these was fixed, and the lower one attached to an index which described an arc, as the helix twisted or untwisted, by the greater expansion or contraction of the silver band over the platinum one. By graduating the range of the index, and finding the value of the indications by comparing them with those of a standard thermometer, the instrument was completed.

Daniell's Pyrometer.—When the temperature is that at which the more infusible metals melt, or of a reverberatory furnace, the common thermometer is unavailable, and other instruments for estimating the heat have been invented, which are called *pyrometers.* Of these, Daniell's register pyrometer, represented in Fig. 1, was formerly much used. It consists of two parts, namely, the register and the scale. The register is a solid bar of black lead, A, highly baked, in the axis of which is drilled a hole reaching to within half an inch of the end; into this hole a bar of iron or of platinum, *a a*, is introduced. A cylindrical piece of porcelain, *c*, sufficiently long to project a short distance from the extremity, is placed endwise upon the iron, and the former is bound to the bar by a band of platinum, *d*, passing round both, and tightened, if necessary, by a wedge of porcelain, *e*. When this instrument is exposed to a very high heat, the whole increases in bulk in proportion to its intensity; but the rate of expansion of the metal and of its casing being unequal, the porcelain cylinder, *c c*, will be protruded to the extent of the difference.

To measure the length of the protruded portion the scale is applied. This consists of two brass rules, *f*, *g*, joined together by screws, to form a right angle, and fitting exactly upon the sides of the register. The plate, *h*, rests on the shoulder of the bar, A, formed for the platinum band. At the extremity of the rule nearest this, an arm, D, movable upon its centre, *i*, is fixed; and at the other an arc of a circle, E, graduated into degrees and thirds of degrees. Upon the latter, at *h′*, is another lighter arm, C, carrying upon the end of its longer limb a nonius, H, which moves upon the face of the arc, E, and subdivides the graduations into minutes. The other end of this arm protrudes beyond the centre of motion, and carries a steel knife-edged bar, which fits into the notch cut for it in the termination of the index.

The index bar is pressed firmly down upon the metal encased in the black lead, and securely fixed there by the wedge and band of platinum; the bar is then nicely adjusted in the angle formed by the two rules of the scale; the plate, *h*, firmly held against the shoulder, and the knife edge, *m*, resting in the notch in the index bar; the position of the latter is now noted on the scale, and after the register has been heated and allowed to cool, the scale is again applied and the result observed—the difference is the value of the expansion of the metal bar. By comparing this with the indications given by a mercurial thermometer between any two points, say that of the freezing and boiling of water, an expansion in degrees of Fahrenheit's scale may be given to any degree of artificial heat measurable by the instrument.

Siemens' Electrical Pyrometer.—The construction and application of this instrument depend upon the increase of the electrical resistance of metallic conductors, with rise of temperature. The first researches made on this subject are those of ARNDSTEN, Dr. WERNER SIEMENS, and Dr. MATTHIESSEN; they were limited to temperatures between 0° and 100° C., and tended to show that the electrical resistance of metallic conductors increased in an *arithmetical* ratio with rise of temperature. Dr. MATTHIESSEN, in later researches, discovered a divergency from this ratio, and expressed it by a formula which, however, has been found not to represent the actual ratio of increase of resistance with rise of temperature. C. W. SIEMENS, D.C.L., F.R.S., the inventor of the above pyrometer, has made researches in this direction, and the formula he has deduced from them is the one which appears to be generally accepted as representing the results of experiments, so far as they have gone. Platinum, which was the metal chiefly experimented on, is found to vary in its resistance with increase of temperature, according as it has been prepared by fusion in a DE VILLE's furnace, or by forging; the latter method of preparation giving the purer metal. The metals were all tested to within a few degrees of the boiling point of mercury, every precaution being taken to keep the temperature constant. The result of a large series of experiments on comparatively pure copper, fused iron (mild steel), silver, aluminium, and platinum, accord in showing that the increase of resistance takes place in a parabolic ratio, expressed by the following formula—

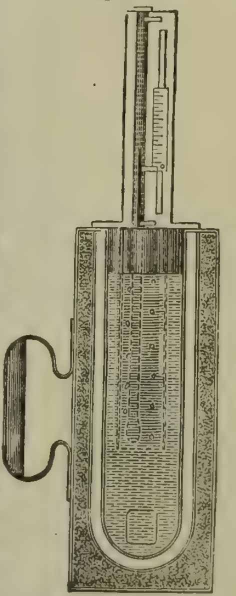
$$R = \alpha T^{\frac{1}{2}} + \beta T + \gamma$$

where R is the resistance at temperature T reckoned from the absolute zero (—274 C.) on the Centigrade scale, and α, β, and γ are constants which vary with the kind of metal and its method of production. The following is a list of metals with arithmetical coefficients:—

$$\begin{aligned}
\text{For platinum—}r &= {\cdot}0021448T^{\frac{1}{2}} + {\cdot}0024187T + {\cdot}30425\\
r &= {\cdot}039369T^{\frac{1}{2}} + {\cdot}00216407T - {\cdot}24127\\
r &= {\cdot}092183T^{\frac{1}{2}} + {\cdot}00007781T - {\cdot}50196\\
\text{For copper—}r &= {\cdot}026577T^{\frac{1}{2}} + {\cdot}0031443T - {\cdot}29751\\
\text{For iron—}r &= {\cdot}072545T^{\frac{1}{2}} + {\cdot}0038133T - 1{\cdot}23971\\
\text{For aluminium—}r &= {\cdot}05951436T^{\frac{1}{2}} + {\cdot}00284603T - {\cdot}76492\\
\text{For silver—}r &= {\cdot}0060907T^{\frac{1}{2}} + {\cdot}0035538T - {\cdot}07456
\end{aligned}$$

It remained to be proved, however, whether the same law would apply to higher degrees of temperature. The following is quoted from a paper in the Transactions of the Society of Telegraph Engineers.

Fig. 2.



"For this purpose I had recourse to a pyrometer, constructed upon the supposition that the specific heat of solids and liquids is the same at all temperatures. An instrument of this description was designed by me some years since, and is used by ironmasters in determining the temperature of their hot blast.

"It is represented at Fig. 2, and consists of a cylindrical vessel of thin sheet copper capable of containing an imperial pint of water. The inner vessel is surrounded by two external vessels of thin metal plate, the narrow space between the first and second being filled with air; and the space between the second and third, or the outer vessel, with cow hair or other non-conductor of heat. A delicate thermometer is fixed against the side of the innermost vessel, being protected from injury by a perforated plate. It is provided with a sliding scale having divisions equal in breadth to the degrees on the thermometer, but each division counting as the equivalent of 50 degrees. A copper or platinum ball is provided, the weight of which is so adjusted that the heat capacity of 50 balls is equal to that of an imperial pint of water at ordinary temperature. This is dropped into the vessel, and the sliding scale thereupon fixed, so that its zero index shall coincide with the position of the mercury level in the thermometer tube. The copper or platinum ball is perforated, in order that it may be placed at the end of a rod to be exposed to the heat which is intended to be measured.

"Upon being fully heated, the ball is dropped into the water, and the reading indicated upon the sliding scale, added to that of the mercury thermometer, gives the temperature of the ball.

"Although a high degree of accuracy cannot be claimed for this instrument, its indications are, nevertheless, useful for obtaining fixed ratio indications of the higher temperatures. It has enabled me to test the general accuracy of the ratio of increase of electrical resistance beyond the limits of the more correct tests obtained at the lower temperatures. The accuracy of these corroborative results depends upon the supposition that the specific heat of the metal ball is the same at high and low temperatures; but although this may not be strictly speaking the case, there is evidence to show that the variations are not of serious import, except probably in nearing the melting points.

"The following are some comparative results which have been obtained by placing in the same heated chamber a copper ball of known capacity of heat, and a coil of platinum wire wound in the spiral grooves of a porcelain cylinder, and protected from injury by a cylindrical casing of platinum. Both the copper ball and the protected spiral wire were placed inside the heated chamber in a piece of wrought-iron tubing, to insure more complete identity of temperature when the resistance of the spiral was taken, and the copper ball dropped into the apparatus just described. The following are some of the results :—

Observed temperature by copper ball pyrometer.	Observed resistance of coil when heated.	Resistance of the same coil at 0° C.	Temperature of coil according to formula $r = {\cdot}0021448T^{\frac{1}{2}} + {\cdot}0024187T + 0{\cdot}50425$.	Difference.
835 C.	30·5	10·56	811° C.	—24°
854 C.	32·0	10·56	882° C.	+28°
810 C.	29·6	10·56	772° C.	—38°

"It remains to be proved whether the law of increase of electrical resistance, which I have here ventured to put forward, holds good for all conductors; and whether it may be trusted at temperatures approaching either the point of absolute zero or the melting point of the metal under consideration. The whole subject, indeed, requires further and fuller investigation than I could devote to it with the principal object of my investigation in view, which, having been the construction of a reliable instrument for measuring low and high temperatures by electrical resistance, I have followed up this branch of the inquiry only to such a point as to supply a tolerably reliable basis for such practical purposes."

We have given this short abstract in order that the reader may be in a position to judge of the experimental basis upon which the instrument is founded.

The first employment of electrical resistance for the measurement of temperature was made in 1860, when Dr. SIEMENS was professionally engaged by Her Majesty's government in superintending the examination of the electrical condition of the Alexandria and Malta Telegraph Cable, during manufacture and submersion. By means of insulated coils of copper wire of standard electrical resistance, protected by iron casings which were placed in various parts of the cable, coiled in the ship's hold, a rise of temperature was discovered which would have destroyed the insulation had not water been copiously poured upon the cable. The result of this practical and important test has been the employment ever since of watertight tanks for carrying submarine cables. From this has also originated various forms of electrical thermometers for measuring temperature at a distance, and also beneath water and underground, designed by SIEMENS, and which are described in the paper above referred to. We now proceed to describe the electrical pyrometer and voltameter in SIEMENS' own language.

The very high degree of heat to which pyrometers have to be raised renders it necessary to construct them as nearly indestructible by fire as possible, and of a material which is not liable to any permanent change by sudden variations in and elevation of temperature. Platinum is a metal which is well suited for this purpose in every way, as it does not, when annealed, alter its specific electrical conductivity by the application of heat; whilst the variation of its measured resistance, due to change of temperature, is sufficiently great to allow of exact readings. But special precautions had to be observed in providing a resistance wire of suitable quality, and in protecting the same from the hot gases of furnaces, which would exercise a chemical action upon it.

The pyrometer coil which I prefer is made of fine platinum wire of 0·01 inch diameter, the resistance of which averages 3·6 units per yard of length. This wire is coiled upon a cylinder of hard baked pipe-clay in which a double threaded helical groove is formed, to prevent the convolutions from coming into contact with each other. The form of pipe-clay cylinder is shown in Fig. 3. At each end of the spiral portion, B B, it is provided with a ring-formed projecting rim, *c* and *c′*, the purpose of which is to keep the cylinder in place when it is inserted in the outer metal case, and to prevent the possibility of contact between the case and the platinum wire. Through the lower ring, *c′*, are two small holes, *b b′*, and through the upper portion two others, *a a′*. The purpose of the upper holes, *a a′*, is for passing the ends of the platinum wires through, before connecting them with the leading wires. From these two holes, downwards, platinum wires are coiled in parallel convolutions round the cylinder to the bottom, where they are passed separately through the holes, *b b′*. Here they are twisted, and by preference fused together by means of an oxy-hydrogen blowpipe. At this end, also, the effective length and resistance of the platinum wire can be adjusted, which is accomplished by forming a return loop of the wire, and providing a connecting screw-link of platinum, L, by which any portion of the loop can be cut off from the electric circuit.

Fig. 3.

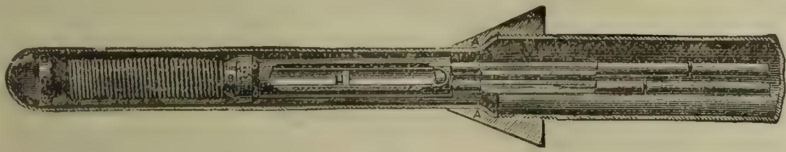
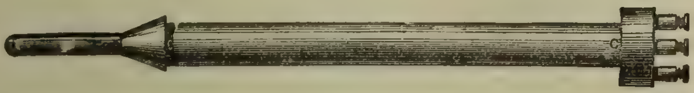


Fig. 4.



The pipe-clay cylinder is inserted in the lower portion, A A, of the protecting case, shown in Fig. 4. This part of the case is made of iron or platinum, and is fitted into the long tube, C C, which is of wrought iron, and which serves as a handle. When the lower end of the casing is of iron, there is a platinum shield to protect the coil on the pipe-clay cylinder. The purpose of the platinum casing is to shield the resistance wire against hot gases and against accident. At the points, A A, Fig. 4, the thick platinum wires are joined to copper connections, over which pieces of ordinary clay tobacco-pipe tube are drawn, and which terminate in binding screws fitted to a block of pipe-clay, closing the end of the tube. A third binding screw is provided, which is likewise connected with one of the two copper connecting wires, and which serves to eliminate disturbing resistances in the leading wires.

If temperatures not exceeding a bright red heat are to be measured, the platinum protecting tube may be dispensed with, and iron or copper substituted.

The pipe-clay tube was found to be highly insulating when cold; when heated, its conducting power increases, though not to such an extent as to occasion any perceptible error.

In adapting the pyrometer to the measurement of high temperatures, a wide range of resistance is obtained, and it is no longer necessary to determine these resistances with the same precision as in measuring slight variations of ordinary temperature; and the use of galvanometers employed in the electrical thermometers already referred to is dispensed with, for which is substituted the differential voltameter, which is thus described.

It consists of two similar narrow glass tubes, A and B, of about 2·5 millimétres in diameter, fixed vertically to a wooden frame, F, with a scale behind them divided into millimétres or other divisions. The lower ends of these tubes are enlarged to about 6 millimétres in diameter, and each of them is fitted with a wooden stopper saturated with paraffin and pierced by two platinum wires, the tapered ends of which reach about 25 millimétres above the level of the stopper. These form voltametric electrodes.

From the enlarged portions of each of the two voltameter tubes a branch tube emanates, connected by means of an india-rubber tube, the one to the movable glass reservoir, G, and the other to G′, Fig. 5. These reservoirs are supported in sliding frames by means of friction springs, and may be raised and lowered at pleasure. The upper extremities of the voltameter tubes are cut smooth and left open, but weighted levers, L and L′, are provided, with india-rubber pads, which usually press down upon the open ends, closing them, but admitting of their being raised, with a view of allowing the interior of the tubes to be in open communication with the atmosphere. Having filled the adjustable reservoirs with dilute sulphuric acid, on opening the ends of the voltameter tubes, the liquid in each tube will rise to a level with that of its respective reservoir, and the latter is moved to its highest position before allowing the ends of the tubes to be closed by the weighted and padded levers.

The ends of the platinum wire forming the electrodes may be platinized with advantage, in order to increase the active surface for the generation of the gases.

Fig. 5.

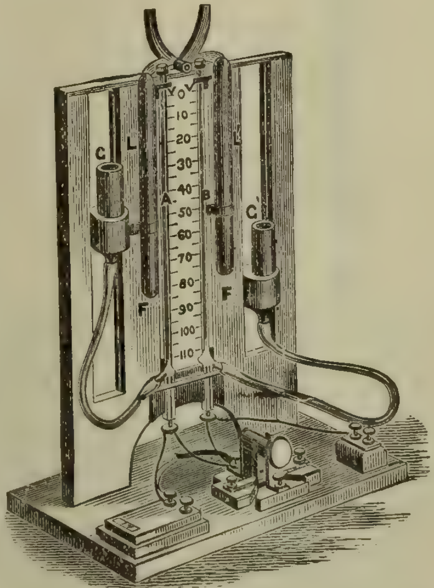
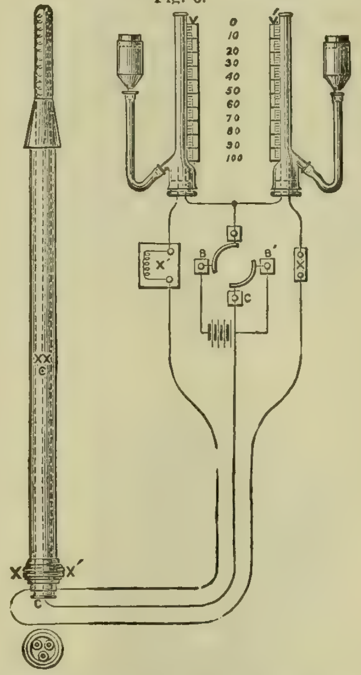


Figure 6 represents the connections of the voltameter with the pyrometer, and also shows the necessity for the third leading wire. One electrode of each voltameter is connected with a common binding screw, which latter may be united at will to either pole of the battery, whilst the remaining two electrodes are, at the same moment, connected with the other pole of the same battery; the one through the constant resistance coil, x, and the other through the unknown resistance, x′. This unknown resistance, x′, is represented to be a pyrometer coil.

By turning the commutator seen at Fig. 5 either in a right or left hand direction from its central or neutral position (in which position the contact springs on either side rest on ebonite), the current from the battery flows through the two circuits, causing decomposition in the voltameters; and the gases generated upon the electrodes accumulate in the upper portions of the graduated tubes. By turning the commutator half round every few seconds the current from the battery is reversed, which prevents polarization of the electrodes. When through the position of the commutator the current flows from the copper, it passes first through the connected electrodes to the voltameters, where it divides, one portion passing through the constant resistance, x, through the leading wire, x, to the pyrometer, returning by the leading wire, c, to the battery, the other passing through x′, through the leading wire, x′, through the platinum coil, returning by the leading wire, c, to the battery. When the current flows from the zinc it passes first through the leading wire, c, the current dividing at the pyrometer, one portion returning by the leading wire, x, through the constant resistance, x, through one voltameter tube to the battery, and the other through the platinum coil, x′, through the leading wire, x′, to the voltameter tube, and thence to the battery. The value of the third leading wire, c, in eliminating the disturbing effect which long and short leading wires with varying temperature would certainly have upon the correct indications of the instrument, is at once evident.

Fig. 6.



The action of this instrument depends upon the combination of Faraday's law of decomposition—

$$I = \frac{V}{t}$$

I being the intensity of the current, V the volume of liquid decomposed, and t the time of action of the current, with Ohm's

$$I = \frac{E}{R}$$

where E represents the electro-motive force, and R the resistance of the electric circuit.

The relative volumes, v and v', of the gases accumulated in an arbitrary space of time within each tube must be inversely proportional to the resistances, R and R′, of the branch circuits, because

$$v : v' = \frac{E}{R}\,t : \frac{E}{R'}\,t,$$

and, therefore,

$$v : v' = R' : R.$$

The resistances, R and R′, are composed, the one of the resistance C, plus the resistance of the voltameter A, and the other of the unknown resistance, X, plus the resistance of the voltameter, B. But the instrument has been so adjusted that the resistances of the two voltameters are alike, being made as small as possible, or equal to about 1 mercury unit, to which has to be added the resistances of the leading wires, which are also made equal to each other, and to about half a unit; these resistances may therefore both of them be expressed by γ.

We have, then—

$$v' : v = C + \gamma : X + \gamma,$$

or—

$$X = \frac{v}{v'}(C + \gamma) - \gamma \qquad (1)$$

which is a convenient formula for calculating the unknown resistance from the known quantities C and γ, and the observed proportion of v and v'.

In order to work this instrument between wide ranges of temperature, it is necessary to make C variable and nearly equal to X. It is necessary to take the following precautions in order to insure reliable results: to employ dilute acid of the same strength in both tubes, to test after disuse by passing a current through with equal resistances in the branches, to use battery power proportional to the resistance (never less than 5 Daniell's elements, to avoid large opposing electro-motive force by polarization), to use resin, cerate, or other waxy substance below the india-rubber pads to prevent escape of gas. A table has been prepared which gives the temperature corresponding to the volumes of the gases of decomposition observed in the tubes, thus saving all calculation on the part of the metallurgist or other observer.

Expansion of Liquids.—In liquids the expansion produced by heat is much more marked than in solids; they also differ among themselves in the amount of expansion produced by equal increments of heat. The most volatile liquids, or those of which the boiling point is low, are found to be the most expansible, as may be observed from the appended table, showing the comparative increase in volume of several liquids when heated from 32° F. to 212° F.:—

Water,..............................	0·0466	Dalton.
Saturated solution of chloride of sodium,	0·0500	"
Concentrated sulphuric acid............	0·0600	"
Hydrochloric acid, spec. grav. 1·137,...	0 0600	"
Nitric acid, spec. grav. 1·40,...........	0·1100	"
Alcohol, spec. grav. 0·817,............	0·1100	"
Ether,................................	0·0700	"
Oil of turpentine,.....................	0·0700	"
Fat oil,...............................	0·0800	"
Mercury,..............................	0 02000	"
"	0·01887	Cavendish.

With reference to the second law which governs the expansion of liquids, namely, that they are progressively more expansive at higher than at lower temperatures, it is to be remarked that in this respect considerable difference exists between different liquids; and in mercury the higher expansion at higher temperatures is less than in any other fluid body. Hence it is better adapted than any of them for the construction of thermometers.

Water, within the range of its solidifying point and that at which it becomes an elastic vapour, is subject to very great irregularities. The general law, as before expressed, is that heat exerts an expansive force upon all bodies; but within a certain range water becomes an exception. If this liquid be taken in the solid state, or at a temperature of 32° F. before it has solidified, and heat be communicated to it, instead of expanding it actually contracts until it marks about 39·4° F., at which it has attained its greatest density. Above this it expands in the same ratio that the contraction took place for an equal number of degrees, but beyond that point it obeys the general law.

The dilatation of water, when reduced in temperature below 39·4° F., serves a purpose of the greatest consequence in the economy of nature, namely, in preventing the transmission of cold beyond the surface of the water in very rigorous seasons, and preserving the chief bulk of the fluid at such a temperature as is congenial to the life of the animals that inhabit it. The fusible alloy of ROSE possesses properties in some respects analogous to water. This substance increases in bulk till it reaches about 111° F., after which it contracts when its temperature is being raised from this to 156°, the point of its greatest density, and at which its bulk is less than when at the freezing point of water; after this, however, it continues to expand till it reaches its fusing point at 201° F.

Expansion of Gases.—The third class of bodies to be considered in relation to the expansive force of heat are gases. All these being, at ordinary temperatures, in a state in which the atomical aggregation manifests a highly repulsive tendency, it is evident that they will be influenced to a greater extent by heat than either of the foregoing classes. A remarkable coincidence or uniformity, however, is found to exist among the different members of this class; and knowing the rate of expansion of one, the same may be taken as the expansive power of the other permanent gases when subjected to an equal increase of temperature. By former investigations this was found to amount to about 375 parts in 1000 of air, when heated from the freezing to the boiling point of water; later researches, however, have shown that the true expansion of air within these limits is 365 parts, or $\frac{1}{493 \cdot 2}$ of the whole for each degree of Fahrenheit's scale. Below the freezing and above the boiling point of water the expansion is in the same ratio. It was found, however, by MAGNUS and REGNAULT, that the operation of this law is not perfectly uniform, especially with reference to the easily liquefied gases, which are more expansible than air when exposed to equal increments of heat, as the following table will show:—

TABLE OF EXPANSION OF GASES BETWEEN 32° AND 212° Fahr.

Names of Gases.	From Experiments at Constant Volume.	From Experiments at Constant Pressure.
Air,...............	0·3665	0·3670
Nitrogen, ...	0·3668	—
Hydrogen,.........	0·3667	0·3661
Carbonic oxide,....	0·3667	0·3669
Carbonic acid, ...	0·3688	0·3710
Nitrous oxide, ...	0·3676	0·3720
Cyanogen, ...	0·3829	0·3877
Sulphurous acid,...	0·3845	0·3903

A sensible increase in the rate of expansion is also found when the gas is submitted to pressure, compared with that which takes place when it is in a rarefied state.

The expansion of perfect gases has been employed in the enunciation and perfecting of a new scale of temperature, known as the absolute scale of temperature. A passing reference has been made to the air thermometer, whose principle will now be explained. The air thermometer consists of a long tube of uniform bore, closed at one end, in which is contained air separated from the outer air by some liquid capable of moving along the tube; the contained air must be kept at constant pressure. If the air thermometer is surrounded with ice-cold water the upper surface of the air will stand at a certain point, which may be marked 0° or 32°, according as the Centigrade or Fahrenheit scale is employed; if it is then placed in boiling water the surface of the air will rise in the tube, and the point may be marked 100° C. or 212° Fahrenheit. If we now continue to graduate the scale we shall arrive at the bottom of the tube. It is known from REGNAULT'S experiments that the distance of the bottom of the tube from the freezing and boiling points respectively are as 1 to 1·3665, hence we can find from calculation that the bottom of the tube must be marked —454° Fahr. or —272·85° C. This point is the absolute zero of temperature already referred to as that at which there is a disappearance of gaseous tension.

Conduction and Convection of Heat.—Another point of great importance is the comparative facility with which heat is conveyed or conducted through different bodies. This property of heat, although by many supposed to be due to radiation, owing to the particles of matter not being in absolute contact, is, however, generally acknowledged to be due to a distinct action, that of conduction. It is upon this principle that nature protects every species of animal and vegetable life against the injurious influence of meteorological changes. The differences observed in the physical appearance of man and of other races of animals, according to their position on the globe, are ordered in conformity with the laws which regulate the conduction of heat; and the means adopted by various nations for shielding their persons from the opposite extremes of heat and cold, as also the covering of every indigenous species of living being, no matter of what class or kind, are all most admirably suited to the state and condition in which they live.

Dense and heavy substances are generally good conductors; light and porous bodies have this property only imperfectly. This may be proved by taking metallic rods, to which small balls of wax are attached at different distances, and introducing one end of them into the flame of a candle. As the heat proceeds from one particle of the metal to another its progress may be measured by the falling off of the balls successively, owing to the wax being melted by the heat. But if cylinders of wood, glass, or wax, be heated in a similar manner, a different result will be observed, owing to the latter being bad conductors of heat.

DESPRETZ instituted a series of experiments for determining the conducting power of metals. His method was to drill holes, at the distance of 3·93 inches apart, in bars of the metal of an equal and determinate thickness; into these holes thermometers were inserted, and the ends of the metals then applied to a heating medium. Later experiments have been made on the same principle by WIEDERMANN and FRANZ and CALVERT and JOHNSON, whose results are embodied in the following table. Principal FORBES studied the variation of thermal conductivity with variation of temperature, and was also the first to discover the similarity of bodies with regard to their thermal and electrical conductivity. His results were confirmed by WIEDERMANN and FRANZ, and are tabulated below.

Temperature (C.).	Conductivity (units, foot-minute-degree).	
	1¼ in. bar.	1 in. bar.
0	·01337	·00992
25	·01235	·00943
50	·01144	·00904
75	·01070	·00865
100	·01012	·00835
125	·00966	·00813
150	·00934	·00795
175	·00904	·00779
200	·00876	·00764
225	·00851	·00749
250	·00826	·00736
275	·00801	·00724

Name of Metals.	Electric Conductivity.			Thermal Conductivity.
	Riess.	Becquerel.	Lenz.	
Silver,	100 0	100·0	100·0	100·0
Copper,	66·7	91·5	73·3	73·6
Gold,	59·0	64·9	58·5	53·2
Brass,	18·4	—	21·5	23·6
Tin,	10·0	14·0	22·6	14·5
Iron,	12·0	12·35	13·0	11·9
Lead,	7·0	8·27	10·7	8·5
Platinum,	10·5	7·93	10·3	6·4
German silver,	5·9	—	—	6·3
Bismuth,	—	—	1·9	1·8

CONDUCTING POWER FOR HEAT.

Metals Employed.	Calvert and Johnson.		
		Wiedermann and Franz.	
	Rise of Temp. (C.)	Mean Conductivity. Silver = 1000.	
Silver,	31·90	1000	1000
Gold,	31·30	981	532
Gold $\frac{994}{1000}$,	26·80	840	—
Rolled copper,	26·95	845	736
Cast copper,	25·87	811	—
Aluminium,	21·20	665	—
Rolled zinc,	20·45	641	—
Cadmium,	18·40	577	—
Bar iron,	13·92	436	119
Tin,	13·45	422	145
Steel,	12·65	397	116
Platinum,	12·15	380	84
Sodium,	11·65	365	—
Cast iron,	11·45	359	—
Lead,	9·17	287	85
Antimony,	6·85	215	—
Bismuth,	1·95	61	18

Glass, although a substance of moderate density, is a bad conductor. The conducting power of a body is much diminished by its being pulverized; thus, metallic filings are worse conductors than bars of the same material; pounded glass and sawdust are also inferior in this respect to solid rods of glass or wood.

The following are the results which HUTCHINSON obtained in his researches on the conducting powers of building materials. The substances are arranged in the order in which they resist the passage of heat, the best non-conductors being placed first:—

Name of substance.	Conducting power referred to that of slate equal 100.
Plaster and sand,	18·70
Keene's cement,	19·01
Plaster of Paris,	20·26
Roman cement,	20·88
Beech wood,	22·44
Lath and plaster,	25·55
Fir wood,	27·61
Oak wood,	33·86
Asphalte,	45·19
Chalk (soft),	56·38
Napoleon marble,	58·27
Stock brick,	60·14
Bath stone,	61·08
Fire brick,	61·70
Painswick stone, H.P.,	71·36
Malm brick,	72·92
Portland stone,	75·10
Lunelle marble,	75·41
Bolsover stone, H.P.,	76·35
Norfal stone, H.P.,	95·36
Slate,	100·00
Yorkshire flag,	110·94
Lead,	521·34

Besides the use which is made of the property of non-conduction in architecture, there are other departments of the arts and manufactures in which it subserves important purposes. Thus, it is applied with good effect in constructing fireproof edifices or apartments, and in the manufacture of chests and boxes intended to preserve valuable property, legal documents, &c., from the destructive effects of conflagration.

Liquids in general are bad conductors of heat; it was formerly asserted, indeed, by some chemists, that water is an absolute non-conductor; it has been proved, however, that liquids conduct heat in some measure, subject to the same laws as solids, although, as regards water and other such mobile liquids, very feebly.

Water conducts heat very slowly from above downwards. The effect observed is very different when, instead of applying heat at the upper surface, it is communicated to the under part, or to the bottom of a vessel in which liquid is contained. In this case the particles in immediate contact with the heat-giving body are expanded. This, by rendering them lighter than the surrounding ones, causes them to ascend; fresh particles succeed, and these rise in similar manner. Currents are thus determined in the liquid, and the whole mass is readily heated. This, however, is not a case of conduction from particle to particle; neither is it due to radiation, which will be afterwards explained; but is the effect of *convection*—that is to say, the actual conveyance or distribution of the heated portion throughout the mass.

Apart from the consideration of the useful purposes to which the convection of heat is applied in the arts, such as the heating and ventilation of buildings, a far more important end is served by it in the economy of nature. During the frosts of winter the process of cooling goes on downward from the surface of the earth and water. The colder water at the top becoming condensed, and consequently heavier than that beneath, sinks and gives place to the latter; this goes on as long as the atmosphere remains at a low temperature, till the water is reduced to its maximum density, a point which it attains at 39·4° F. It is a remarkable circumstance, and forms a singular exception to the general law, that water when cooled to this point begins to expand, and consequently remains at the surface. When cooled to 32° F. it freezes, and during its conversion into ice it experiences a still further expansion, so that the ice, instead of sinking to the bottom, and there accumulating in dense masses, floats on the surface till melted—one of the most wonderful provisions for the preservation of life in the economy of nature.

In their mode of conducting heat, gases resemble liquids; that is to say, their power of actual conduction is inappreciable; but by their property of convection, currents are instituted by which the heat is disseminated throughout the mass. To observe this, it is only requisite to hold the hand first at the side of a lighted candle and then above it, the distance in both cases being equal; it will be perceived that in the first position little heat is received, whilst in the second the increase of temperature is immediately obvious, the greater portion of the heat being carried off in the ascending current, which in gases is more active than in liquids, owing to their power of expansion being so much greater. The application of these currents of heated air is of great practical importance in the ventilation of dwellings and public buildings. Indeed, in every species of human habitation provided with a fire-place and chimney, the latter operates as a ventilating apparatus. The heat derived from the combustion of fuel in the grate or on the hearth dilates the super-imposed atmosphere, and causes its ascent in the shaft, while an influx of air to the fire supplies its place. The transmission of smoke and warm air through the chimney soon raises its temperature, and on this account the heat which is received from the fire is retained by the vapour till it passes out at the top. The force of the current or *draught* thus formed will be in proportion to the greater expansion of a column of air of the height of the chimney than that of an equal column externally. Common air, like other gases, increases about one five-hundredth of its bulk for each degree Fahr. of temperature which it acquires; hence, by ascertaining the internal temperature and height of the chimney, the force of the ascending atmospheric column may be calculated.

Radiation of Heat.—On the whole, it may be laid down as a general law that air, the gases, water, and fluids generally, with the exception of mercury, are bad conductors of heat, notwithstanding that it is distributed readily by them in the manner already explained. Although, however, it is the natural tendency of convection to operate upwards, yet if the hand or the bulb of a sensitive thermometer be placed at some distance beneath a warm body, or on either side of it, an increase of heat will be indicated. From this it is evident, that though the permanent gases and the atmosphere do not sensibly conduct heat, yet, in common with liquids and other transparent bodies, they permit its passage without being themselves appreciably affected by it. All the heat received by the earth from the sun—the amount of which, to each acre in the latitude of London, is calculated by FARADAY to be equivalent to that which is generated by the combustion of sixty sacks of coal—thus travels through the intermediate space of ninety-five millions of miles without sensibly affecting the temperature of the atmosphere, or that of the subtle medium beyond it. When heat emanates from any body in this way, it is said to be radiated from it, and is denominated *radiant heat.* Thus, if a bar of heated metal be suspended in a room for some time heat will radiate in all directions, until the metal ultimately indicates only the same temperature as the surrounding objects. During the cooling the heat passes off at all points of the body in direct lines from a centre, hence the term *radiated.* To prove that convection and radiation are distinct processes, and that the latter is not a consequence of the former, all that is necessary is to expose a heated body in the vacuum of an air-pump, in which case it will be observed that the emission of heat is much quicker even than if it were allowed to cool in contact with the air.

In simple language, the rate of cooling expresses the radiating power; and Leslie ascertained that the radiating power of bodies was more influenced by the state of their surface than by the nature of the material. A bright tin globe filled with water at a certain temperature was allowed to cool, and the time being carefully noted, it was found that the contents of the vessel cooled half way to the temperature of the room in one hundred and fifty-six minutes. When the same experiment was repeated with the surface of the globe coated with lamp-black, it was observed that the mercury in the thermometer fell through the same space as it did in the first experiment in eighty-one minutes; thus showing that by the alteration of the surface the radiating power was doubled. Count Rumford corroborated this observation by another experiment. Taking two brass cylinders of equal size and capacity, and investing one of them tightly with linen, while the other was left bare, he filled the two with boiling water and allowed them to cool. During this process he observed that the coated cylinder lost 10° of its original temperature in thirty-six minutes and a half, while the other required fifty-five minutes to pass through an equal range.

By following the method of Leslie and Count Rumford in the foregoing experiments, namely, coating the heated surface with various materials, and observing the time required in cooling, or, as will be presently noticed, by concentrating the rays radiated from a certain extent of surface, and ascertaining their intensity by their action upon a delicate thermometer, the comparative radiating power of different bodies may be ascertained. By this method it has been found that lamp-black is superior in radiating power to any other substance hitherto submitted to experiment, and that if this be represented by 100

Writing paper will be	98
Resin,	96
Sealing wax,	95
Crown glass,	90
Indian ink,	88
Ice,	85
Islinglass and red lead,	80
Plumbago,	75
Tarnished lead,	45
Polished lead,	19
" tin plate, gold, silver, copper,	12

From this table it will be seen that lamp-black irradiates five times as much of the heat of boiling water as clean lead, and eight times more than bright tin. The general low radiating power of the metals is increased if these be allowed to tarnish, as exhibited in the case of lead in the preceding table. Smoothness of surface, however, does not always act in relation to other bodies as it does in metals, for glass and porcelain, although their surface is smooth, always radiate very powerfully. When the actual radiating surface is metallic, it is not affected in a sensible manner by the substance under it; thus glass, coated with gold leaf or tinfoil, possesses the radiating power of the superimposed metals.

Specific Heat. — Bodies have different capacities for heat; or in other words the application of the same amount of heat will elevate the temperature of diverse substances unequally. The *specific heat* of a body is the ratio of the quantity of heat required to raise that body 1° to the quantity required to raise an equal weight of water 1°. If a certain weight of water, at the ordinary temperature of the atmosphere, be mixed with an equal quantity of this liquid raised to a higher degree, the mixture will indicate a mean between these extremes; but if another liquid, such as oil or mercury, be added, instead of the second portion of water a great difference will be observed. When a measure of water at 60° F. is agitated with as much mercury at 140° F., the compound, instead of marking 100° F. as in the preceding case, will indicate only 86·6° F. Again, if mercury at 40° F. be added to an equal bulk of water at 156° F., the heat of the latter is reduced by 3·7° F., which, being absorbed by the fluid metal, raises it to 152·3° F., so that each degree which the water indicates by the instrument has the effect of 30·35° F. upon the fluid metal. Taking, then, the capacity of water for heat to be unity, that of mercury will be found from the above results to be 0·033. The capacity of any other body for heat may be determined with tolerable accuracy in the same way; the sides of the vessel, however, are liable to radiate more or less heat, and will, of course, cause a slight deviation from absolute accuracy in the results.

Many plans have been proposed for estimating the capacity of bodies for heat. The method just described was followed by Wilke, Crawford, Kirwan, Dalton, and others; whilst Delaroche, Berard, Neumann, and Regnault proceeded on the principle of allowing equal weights of bodies to be exposed to the same cooling medium, and observing the difference in the time which they require to fall to the same degree; or, inversely, the time was noted which the bodies, when subjected to the same temperature, required to arrive at the marked degree. The difference, of course, depended upon the capacity for heat, and from this datum the latter was relatively estimated.

In the experiments of Lavoisier and Laplace, the body employed for this purpose was pounded ice, which was so applied around a globe as to intercept all the heat. Fig. 7 shows a section of their apparatus, which they termed a *calorimeter*. The heating power was estimated in this case from the quantity of water produced by the melting of the ice, and which flowed into the receivers, as seen in the engraving.

But this method was likewise liable to error, for the ice retains a portion of water which has been liquefied, and, therefore, the measurement of the quantity dissolved cannot afford a perfectly correct estimate; besides, portions of what has been rendered fluid are liable to be frozen again, and in either case the results must be incorrect. Dulong and Petit conducted their researches by allowing spheres of equal size, equally heated, to cool, and noting the time they required to fall to a given point; this, of course, will depend upon the relative heat, provided the radiation is rendered equal.

The following table shows the specific heat of the substances mentioned, between 32° and 212° Fahr.:—

Name.	Specific heat; water = 1°.	Authority.
Arsenic,	0·0814	Regnault.
Antimony,	0·0508	"
Animal charcoal,	0·2608	"
Charcoal strongly ignited,	0·2415	"
" moderately heated,	0·2964	De la Rive and Marcet.
Bismuth,	0·0308	Regnault.
Bromine,	5·1350	De la Rive and Marcet.
Cadmium,	0·0567	Regnault.
Copper,	0·0951	"
Cobalt,	0·1069	"
Coke—from gas retorts,	0·2023	"
" Anthracite, containing 3 per cent. of ash,	0·2017	"
" from Cannel coal, containing 4 to 5 per cent. of ash,	0·2031	"
Diamond,	0·1469	"
Glass,	0·1976	"
Gold,	0·3244	"
Graphite, natural,	0·2019	"
Graphite, artificial,	0·1970	"
Iodine,	0·0541	"
Iron,	0·1137	"
Ice,	0·5130	"
Iridium,	0·0368	"
Lead,	0·0314	"
Manganese, containing carbon,	0·1414	"
Mercury,	0·0333	"
Molybdenum,	0·0722	"
Nickel,	0·1086	"
Palladium,	0·0593	"
Platinum,	0·0324	"
Phosphorus,	0·1887	"
Selenium,	0·0837	"
Sulphur,	0·2026	"
Silver,	0·0570	"
Tellurium,	0·0515	"
Tin,	0·0562	"
Tungsten,	0·0364	"
Uranium,	0·0619	"
Zinc,	0·0955	"

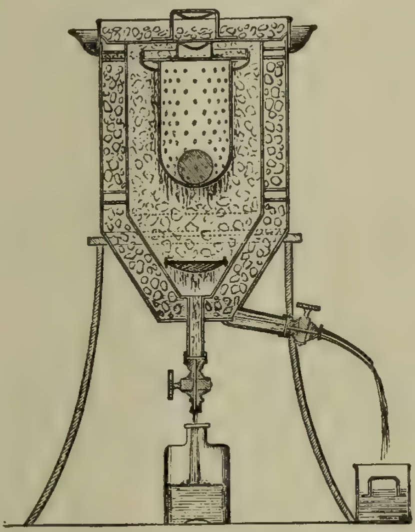
The specific heat of bodies varies with their state of expansion, or, in other words, with any alteration in the distance of their particles from each other. Mechanical compression, sufficient to produce a permanent alteration in density, is attended by a corresponding decrease of specific heat. Regnault found the capacity for heat of a piece of soft copper to be, in two experiments, from 0·09501 to 0·09455; but after subjecting it to an atomical disarrangement by hammering, the specific heat diminished, and became 0·0936 to 0·0933. When, however, the original state of the bar was restored by annealing an increase was experienced, and two trials gave respectively 0·09493 and 0·9479.

Elevation of temperature also increases the capacity of bodies for heat, and hence it requires the application of a greater heat to raise their temperature when heated. The appended table shows the increasing specific heat of the bodies enumerated within the limits assigned:—

Name.	Specific heat between 32° and 212°.	Ditto between 32° and 572°.
Mercury,	0·0330	0·0350
Platinum,	·0335	·0355
Antimony,	·0507	·0549
Silver,	·0557	·0611
Zinc,	·0927	·1015
Copper,	·0949	·1013
Iron,	·1098	·1218
Glass,	·1770	·1900

Water ranks first of all bodies yet known in its increasing capacity for heat at an elevated temperature. Between 22° and 32° Fahr. the specific heat of solidified water is 0·505, assuming it to be unity in the liquid state, and if converted into steam the specific heat of the vapour increases with its state of dilatation. This property contributes in no small degree towards moderating the rapidity of the transitions from heat to cold, and *vice versa*, in the atmosphere, owing to the large quantity of heat which is absorbed by or emitted from the water of the ocean when the temperature exceeds or falls short of the normal range.

Fig. 7.



In the determination of the specific heat of vapours much remains to be done to arrrive at satisfactory results.

Dulong and Petit endeavoured to establish the relation of the specific heat of bodies and their atomic equivalent. This relation they expressed by a general law, that the specific heat of elementary bodies varies inversely with their atomic weights; and that an atom of any one simple substance, whether small or large, has the same capacity for heat, and requires the same quantity to raise its temperature through a given number of degrees, as an atom of any other element. Regnault, by observing that the product of the specific heat into the atomic weight is nearly a constant quantity, represented by 3·2, advanced a considerable step towards establishing the existence of this general law; still, there are many exceptions which have not yet been reconciled with it.

The following is a tabulated result of later experiments that have been made, proving DULONG and PETIT'S law to be at least very approximately a statement of a general law:—

SPECIFIC AND ATOMIC HEAT OF THE ELEMENTS.

Elements.	Specific Heat of Equal Weights.	Equivalent.	Specific Heat × Equivalent.	Atomic Weight.	Specific Heat × Atomic Weight.	Weights containing equal quantities of heat.
Diamond,	0·1468	6	0·8808	48 ?	6·0464	44·84
Graphite,	0·2018	6	1·2108	33 ?	6·6594	32·79
Wood charcoal,	0·2415	6	1·4490	—	—	27·27
Silicon, fused,	0·1750	14	2·450	35 ?	6·125	37·63
" crystallized,	0·1767	—	—	—	—	37·12
Boron, crystallized,	0·250	10·9	2·725	—	—	26·34
Sulphur (native),	0·1776	16·0	2·8416	32	5·6832	32·51
Selenium,	0·0837	39·7	3·3145	79·5	6·6541	86·47
Tellurium,	0·04737	64·5	3·0553	129	6·1107	130·02
Magnesium,	0·2499	12·0	2·9988	24	5·9976	26·35
Zinc,	0·09555	32·5	3·1054	65	6·2108	68·92
Cadmium,	0·05669	56·0	3·1741	112	6·3482	116·17
Aluminium,	0·2143	13·7	2·9359	27·5	5·8730	30·73
Iron,	0·11379	28·0	3·1861	56	6·3722	57·87
Nickel,	0·10863	29·5	3·2015	59	6·4090	59·44
Cobalt,	0·10696	29·5	3·1553	59	6·3106	61·23
Manganese,	0·1217	27·5	3·3467	55	6·6934	51·11
Tin,	0·05623	59·0	3·3178	118	6·6356	117·12
Tungsten,	0·03342	92·0	3·0746	184	6·1492	197·06
Molybdenum,	0·07218	48·0	3·465	96	6·931	91·24
Copper,	0·09515	31·7	3·0162	63·5	6·0419	66·21
Lead,	0·03140	103·5	3·2499	207	6·4999	209·73
Mercury, solid,	0·03192	100·0	3·1920	200	6·3840	206·32
" liquid,	0·03332	100·0	3·3320	200	6·6640	—
Platinum,	0·03243	98·6	3·1976	197·2	6·3952	203·07
Potassium,	0·16956	—	—	39	6·6128	38·84
Sodium,	0·29340	—	—	23	6·7480	22·40
Phosphorus,	0·18870	—	—	31	5·8497	34·90
Silver,	0·05701	—	—	108	6·1570	115·52
Gold,	0·03244	—	—	196·6	6·3777	203·01

The above stated law of DULONG and PETIT has been extended to compound bodies. According to REGNAULT'S experiments the alloys have a specific heat the mean of their components, or otherwise equal to the sum of their components. WOESTYN has shown this law to hold for sulphides and iodides, and GARNIER, and latterly and especially KOPP, maintain that the law is true for all bodies.

Latent Heat.—Latent heat is a term which is employed to express a quantity of heat which has disappeared, that is to produce some effect other than rise of temperature; by reversing the effect, the quantity of heat which has disappeared is rendered sensible. The latent heat of expansion is a physical unit which has not been much studied, except in the case of atmospheric air. In this case, to raise the temperature of a pound of air 1° Fahr., and increase its volume ·0020276 of its volume at the freezing point of water, requires 0·238 of a thermal unit, whilst to raise its temperature without expansion requires 0·169. The difference between these quantities, 0·069 of a thermal unit, is the heat which has disappeared or become latent in producing the expansion. Professor RANKINE has stated in reference to this matter:—"The fact already mentioned, that the increase of the specific heat of solids and liquids as the temperature rises, is greatest for those which are the most expansible by heat, and in particular, the instance of that fact which takes place for water, whose least specific heat corresponds to its greatest density, makes it probable that the *variable part* of the specific heat of solids and liquids is the *latent heat* of expansion; and that the *real specific* heat of every substance, or the heat which produces changes of temperature alone, is constant for all temperatures."

Latent heat, the amount of which differs in different bodies, serves very important offices in the economy of nature, as well as in the chemical manufactures. When the temperature of the atmosphere in winter rises to 32°, masses of ice and vast accumulations of snow would suddenly liquefy, producing destructive inundations, were it not that in melting they must further absorb the heat of fluidity, which becomes latent, and thus the change is retarded and rendered gradual. In the manufactures, the importance of latent heat is illustrated by the employment of steam as the heating agent in numerous processes of distillation, evaporation, and carbonization; but the manner in which it acts in these cases will be better understood after some further explanation of the effect of heat upon liquids.

It has been shown that the change from the solid to the liquid form is the result of heat, and that it becomes insensible to the thermometer, however delicate its construction; this is referred to as the latent heat of fusion. Instances of the absorption and disappearance of heat have been given in the melting of ice, metals, and other substances, capable of passing into the liquid state. In the fusion of metals, the temperature of the bath does not increase a fraction of a degree above the melting point till the whole has undergone liquefaction, notwithstanding that heat has been pouring into the mass without intermission. The reason of this is, that as long as any of the metal remains solid, it abstracts all the excess with which the liquid may be charged, and combines with it to form more fluid. After the latter stage has been attained, if the temperature be still increased, the bath will continue to indicate a rising temperature till it acquires that degree at which the repulsive force of the heat will have so far overcome the cohesion of the particles, as to expand them to such an extent that their gravity will be less than that of the air, bulk for bulk. The liquid will then be gradually transformed into vapour, and will manifest the phenomenon of ebullition, which is simply the commotion produced by the evolution of bubbles of the substance itself converted to the gaseous state. Whatever additional heat be now applied, the boiling fluid will continue to indicate the same temperature as long as any of it remains; and during the process the vapour which escapes possesses *apparently* only the same amount of heat as the liquid from which it is produced, but *actually* a greater amount in the shape of the additional *latent heat* by which it is converted into vapour.

These changes are more familiarly known as happening with water than with metals, for although the latter are frequently fused, they are seldom converted into vapour. During the melting of ice by the application of heat, the ice, or mixture of ice and water, remains at 32° F. till the whole is melted; it is evident, however, that the water at 32° F. must now contain more heat than when, in the state of ice, it indicated the same temperature. If heat continue to be applied, the water gradually acquires a temperature of 212° F., at which point, provided the atmosphere is at the usual standard barometric pressure, and the liquid be contained in an open vessel, the temperature remains stationary. The water is now rapidly converted into vapour, but both the liquid and vapour are still at the temperature of 212° F. A little consideration will show that the heat which continues to flow into the liquid is expended in converting it into steam; for as no indication of an increase is manifest, it must be evident that the surplus is rendered insensible in the process of converting the water into vapour. The quantity of heat necessary to effect this is much larger than is required to reduce the body from the solid to the liquid state. To estimate the amount of heat expended and rendered insensible or latent in both cases, let a pound of water at 212° F. be mixed with the same weight of water at 32° F., and it will be found that the mixture will indicate a medium between these points—that is to say, the pound of water at 212° F. will lose 90°, and the pound of water at 32° F. will gain 90°; so that the mixture will indicate 122° F. But now let a pound of water at 212° F. be mixed with a pound of snow or ice at 32° F., and the mixture will indicate only 51° F., showing that the water has lost 161°, while the snow or ice has gained *apparently* only 19°. It is evident that the difference between these figures, or 142°, must have been absorbed or become latent in converting the snow or ice into water.

Applying the same test to steam or vapour of water at 212° F., it will be found that 1 lb. of water, which has been converted into steam, is sufficient to reduce $6\frac{1}{4}$ lbs. of snow or ice to the liquid state, and to raise it to 51°, from which it may be deduced that steam contains 967° of latent or insensible heat, and is distinguished as the latent heat of evaporation.

Ebullition and Evaporation. — During the ebullition of water in common metallic vessels at the ordinary pressure of the atmosphere, no amount of heat applied can elevate its temperature beyond 212°, provided the steam passes off freely; a fact which is well deserving of consideration in domestic economy. Many causes, however, tend to vary the boiling point of water and of liquids in general. If it be contained in smooth glass vessels, ebullition takes place at 2° or 3° above the usual standard; hence, if a coil of wire be introduced into water contained in a smooth glass vessel, and near the point of ebullition, this process will commence immediately. All angular bodies, and more especially metals, introduced among the liquid, cause the boiling to take place even in glass vessels at 212° F. The adhesion of the liquid to the sides of such vessels seems to be the cause of impeding the boiling, and sometimes of making it pass into vapour suddenly; hence in distilling in the laboratory the custom of introducing bits of platinum wire into the retort to facilitate the conversion of the liquid into vapour; without this precaution there is often danger of the retort being broken, or of the liquid operated upon being thrown over into the receiver. At each evolution of vapour that is formed during ebullition under these circumstances, the temperature falls to 212° F.; but when it has escaped, the contents of the vessel remain quiet till the temperature rises as before. Many substances, such as shell-lac, when applied to the interior of the vessel, prevent ebullition taking place at the usual degree; but the experiments of DORMY have proved that atmospheric air mixed with liquids influences their boiling point more than anything else, except pressure. He showed that the air which is dissolved in water acquires an increased elasticity, and forms minute bubbles in the interior of the fluid into which the steam dilates and rises to the surface. By long-continued boiling the air is nearly expelled; and in the course of some experiments it was found that the temperature could be raised to 360° F. in an open vessel without the phenomenon of ebullition taking place; finally, however, the disengagement of vapour was so sudden, that it caused a loud explosive report, and shattered the vessel in fragments.

From what has been said, it is evident that the boiling point of liquids is not fixed, but is dependent upon various causes. The greatest effect is produced by the varying pressure of the atmosphere, which on an average is 15 lbs. for every square inch of surface at the level of the sea; but the weight of the air varies at different heights, and according as it happens to be surcharged with watery vapour or not; consequently, at different elevations the boiling point will be different, and even at the same level the pressure or density varies so much as to cause a difference of 4° or more of Fahrenheit's scale. It is absolutely necessary, therefore, to observe the pressure of the atmosphere when fixing the boiling point of liquids on the thermometer, and to make the necessary corrections. This is done by noting the height at which the mercury in the barometer stands at the time, and making the requisite allowance for any difference between that and the normal height of 29·92 inches, as shown by the following table, which embraces the extreme indications of the barometer at common levels, with the boiling points of water corresponding to these and the intermediate indications:—

Barometer indication. Inches.	Water boils. Deg. Fahr.
27·74	208
28·29	209
28·84	210
29·41	211
29·92	212
30·6	213

It thus appears that under a diminished pressure water boils at a lower temperature, and the same happens with other liquids. Saussure found that on the top of Mont Blanc water boiled at 184° F. In deep mines, on the contrary, it requires a much higher temperature than 212° F. to bring it to a state of ebullition. On this circumstance has been based the construction of an instrument for determining the heights of mountains by the boiling point of water or other liquids.

When the pressure is removed by artificial means, as by creating a vacuum, the boiling point of water may be lowered about 145° F. under the usual temperature at which ebullition takes place. This has been turned to advantage in several manufacturing processes, where an exposure to the temperature of boiling water, under ordinary circumstances, for a length of time, would be prejudicial and sometimes destructive to the substances under treatment. The pharmaceutist and sugar-refiner are especially benefited by the application of this important fact in their respective processes. By operating under a low pressure, produced by creating a partial vacuum, the former can readily evaporate his vegetable juices to any desired extent without injury; whereas, if the same were attempted in an open vessel under the common atmospheric pressure, most of the active principle would be destroyed. In like manner, if the saccharine liquid of the sugar boiler were to be concentrated to the same degree to which it is usually carried in an open pan or boiler, nearly the whole of the crystallizable sugar would, by an allotropic molecular arrangement, pass to an uncrystallizable sirup. By an increased pressure the converse of this happens, and water may be made to attain a temperature of 300°, 400°, or upwards before ebullition. An instrument known as Papin's digester, which is simply a strong metallic vessel with a safety valve, is constructed on this principle, and is used to macerate bones and other substances in liquids raised to a higher temperature than that of boiling water.

Solid bodies dissolved in water or other liquids produce, to a certain extent, the same effect as high pressure; generally, the elevation of the boiling point varies according to the nature of the substance in solution, but it uniformly increases with the same body till the liquid is saturated. Tables founded upon this law have been drawn up, for the purpose of estimating the amount of saline matter in a liquid from its boiling point.

Ebullition consists mainly in the conversion of the liquid into vapour, and so far is synonymous with evaporation; which differs from it, however, inasmuch as the latter takes place at all temperatures—whereas a certain range of heat is required, under every circumstance, before the former phenomenon is observed. This may be proved by allowing a shallow vessel containing water to remain exposed for some time; upon examination it will be found that a portion will have disappeared—or, in other words, it will have evaporated to the extent of the loss. Most fluids are susceptible of this change, but those which boil at a low temperature are more volatile than others; thus alcohol is evaporated much quicker than water, and for the same reason ether is converted into vapour much more readily than even alcohol.

Evaporation is affected by the temperature and hygrometric state of the air, and the extent of surface exposed. It is evident that the latter must influence the rate of conversion into vapour, because this alteration can only take place at the surface: hence the amount of evaporation will be, *cæteris paribus*, in proportion to the superficies which the fluid presents. But when the air is surcharged with moisture, the change into vapour will be slow, even although the temperature be elevated, whereas, if it be dry, the fluid will disappear much quicker. In still air the evaporation is much slower than when a breeze or current of air is passing over the liquid; because in the former case the stratum of air immediately over the surface of the fluid becomes saturated and unable to take up any more moisture, whereas, when a current is established, a fresh and dry stratum is constantly presented to the liquid, and passes away loaded with vapour.

Evaporation, like ebullition, is greatly promoted by the removal of pressure; thus, by placing a cup containing ether or any other volatile fluid under the receiver of the air-pump and exhausting it, the fluid rapidly disappears, and an atmosphere of vapour is formed.

In all cases, however, where it is expedient that liquids should be quickly vaporized, heat is resorted to as the best and most ready agent. Heat, indeed, is the cause of evaporation at whatever degree or under whatever circumstances it takes place, just as it has been shown to be the cause of liquidity. Hence arises the important question, What is the least quantity of heat required to effect the evaporation of a given quantity of liquid?—a question which bears on the economy of fuel in the generation of steam, and in many other manufacturing processes. Sharpe, of Manchester, arrived at the conclusion that as the latent heat of vapour is increased with its degree of rarefaction, and as subtler vapour is obtained at low than at more elevated temperatures, there is no economy of heat, and therefore no saving of fuel by evaporating or distilling liquids *in vacuo.* Watt further showed that the same weight of steam, whatever density it may possess, contains the same quantity of heat, its insensible or latent heat being increased in proportion as its sensible is absorbed. Thus he found that a given weight of steam at 212° F, and consequently possessing 180° of sensible heat above the freezing point, gave off 950° more when condensed by injecting upon it water at 32°, making, with the sensible heat, a total of 1130° above the point of freezing. Again, the same weight of steam at 250°, and therefore possessing 218° of sensible heat, gave out, on being liquefied at the same temperature, only 912° Fahr., which with the sensible heat amounted exactly to 1130° also. This he assumed, therefore, as the amount of heat necessary to convert water at 32° into steam, either of a high or low tension; and hence, on this assumption, to ascertain the amount of latent or insensible heat in steam, at any temperature, all that is necessary is to deduct the sensible heat from 1130°, and the difference is the latent heat.

These experiments appear to lead to the inference that in the evaporation of liquids, generation of steam, distillation, &c., no material economy is gained by conducting these processes at low rather than at high temperatures; but the later and more carefully conducted researches of Regnault have shown that this assumption is not strictly correct, and although the difference does not lead to serious errors in practice, yet in reality the sum of the latent and sensible heat increases for each degree of Fahrenheit by a constant quantity equal to 0·305°. This is illustrated in the annexed table, in which it is assumed that steam possesses no sensible heat below Fahrenheit's zero:—

LATENT AND SENSIBLE HEAT OF STEAM AT DIFFERENT TEMPERATURES:—

Pressure in Atmospheres.	Temperature.	Latent Heat.	Sum of Latent and Sensible Heat.
0·044	0°	1114°	1114°
0·180	32	1091·7	1123·7
1·000	212	966·6	1178·6
8·000	339	877·3	1216·8

The increase here shown offers, however, but a small inducement to perform the processes already alluded to at low temperatures—so far as saving of fuel is concerned; while the increased amount of sensible heat which may be utilized advantageously when the steam is generated under pressure, renders it expedient that the latter mode of generating it should be resorted to. This is the case especially when steam is employed as a source of heat in the carbonization of ligneous matters, in the distillation of liquids, and occasionally in the concentration of saline and extractive solutions. The large amount of heat which steam possesses renders it peculiarly adapted to such purposes; and hence, in all those manufactures where the products are of a salifiable or an attractive nature, steam is now generally employed to concentrate the liquors. In the culinary art, also, it is found to be much more eligible as a source of heat than the common method of exposing the apparatus directly to the action of fire. It is especially adapted for drying manufactured goods and for purposes of ventilation; in the one case, it is conveyed through cylinders over which the goods are conducted, and in the other through iron pipes so disposed that the heat shall be given off in the most effectual way. In the latter case, experience has shown that the boiler should have 1 cubic foot capacity for every 2000 cubic feet of air to be heated to a temperature of 70° or 80° F., and that the conducting pipe must present a superficies of 1 square foot for every 200 cubic feet of space to be heated.

Elastic Force of Steam.—When different liquids are heated to their boiling points, they produce very unequal quantities of vapour. Water yields it in larger volume than any other known liquid. The following table shows the volume of vapour produced by a cubic inch of each of the liquids enumerated at their respective boiling points:—

Cubic Inch.			Cubic Inches.			
1	of water	expands to	1696	at the	boiling	point.
1	of alcohol	"	528	"	"	"
1	of ether	"	298	"	"	"
1	of turpentine	"	193	"	"	"

The great value of machinery at the present day in developing the resources of nations, and in fostering and extending commerce and internal intercourse, turns upon the expansive property of water under the influence of heat. This, as already stated, is such as to make it the most efficient motive power; and although it requires a higher temperature, and consequently a greater consumption of fuel, to generate vapour from it than many other liquids, yet its superior elasticity in the shape of steam is such as to render it preferable to any of them, even supposing they could be had as cheaply. When the vapour of water is heated alone, the rate of expansion is the same as that of air or any other elastic gaseous mixture when subjected to an equal temperature, and it may confined in red-hot vessels without a great amount of elastic force being acquired. It is otherwise, however, if some water be contained in the vessel or cylinder, for then the generation of fresh vapour causes an addition of elastic force to that already exerted, so that in time the pressure on the walls of the vessel becomes irresistible.

Dulong and Arago have made some researches upon this subject which are valuable, inasmuch as they throw considerable light upon the mechanical effect of steam. The results are therefore appended in the following table, from which it may be seen, that as the temperature rises a given increment of heat produces a greater effect in augmenting the elastic force than at a lower temperature. If the atmospheric pressure, or the elasticity of steam at

212° Fahr., be taken as unity, the elastic force of steam at 240° Fahr. will be about one and a half, and at 250° Fahr. will be equal to two atmospheres. Thus an increase in the quantity of heat indicated by 38° Fahr. doubles the elastic force, and it also appears from the table that a further increase of 25° trebles the elastic force, and a further increase of only 18° quadruples it. Thus the elastic force evidently increases much more rapidly than the temperature.

ELASTICITY OF STEAM AT HIGH TEMPERATURES.

Elasticity of steam, taking atmospheric pressure as 1.	Temperature Fahr.
1	212°·0
1·5	239·96
2	250·52
2·5	263·84
3	275·18
3·5	285·08
4	293·72
4·5	300·28
5	307·5
5·5	314·24
6	320·36
6·5	326·26
7	331·70
7·5	336·86
8	341·78
9	350·78
10	358·88
11	366·85
12	374·00
13	380°·66
14	386·94
15	392·86
16	398·48
17	403·82
18	408·92
19	413·78
20	418·46
21	422·96
22	427·28
23	431·42
24	435·56
25	439·34
30	457·16
35	472·73
40	486·59
45	491·14
50	510·60

REGNAULT has made a vast number of experiments for the measurement of the maximum tension of vapours. The apparatus he employed consisted of a copper boiler, connecting by means of a tube slanting upwards with a reservoir which was in communication with a manometer or pressure gauge. The air in the reservoir can be either rarified or compressed, and the temperature at which the water boils is indicated by thermometers. From experiments made with this instrument the following table has been deduced, which will be found on comparison to agree very closely with the preceding one :—

Temperatures, Centigrade.	Temperatures, Fahrenheit.	Tensions in Millimetres of Mercury.	Tensions in inches of Mercury.
— 32°	— 25·6°	0·32	·0126
— 20°	— 4°	0·93	·0366
— 10°	14°	2·09	·0823
— 5°	23°	3·11	·1224
0°	32°	4·60	·1811
5°	41°	6·53	·2571
10°	50°	9·17	·3610
15°	59°	12·70	·5
20°	68°	17·39	·6846
25°	77°	23·55	·9272
30°	86°	31·55	1·2421
35°	95°	41·82	1·6465
40°	104°	54·91	2·1618
45°	113°	71·39	2·8106
50°	122°	91·98	3·6212
55°	131°	117·47	4·6248
60°	140°	148·70	5·8543
65°	149°	186·94	7·3598
70°	158°	233·09	9·1768
75°	167°	288·51	11·3586
80°	176°	354·64	13·9622
85°	185°	433·04	17·0488
90°	194°	525·45	20·687
95°	203°	633·77	24·9515
100°	212°	760·00	29·9212

Temperatures, Centigrade.	Temperatures, Fahrenheit.	Tensions in Atmospheres.	Tensions in lbs. on the Square Inch.
100°	212°	1	14·7
121°	249·8°	2·025	29·7675
134°	273·2°	3·008	44·2176
144°	291·2°	4	58·8
152°	305·6°	4·971	73·0737
159°	318·2°	5·966	87·7002
171°	339·8°	8·036	118·1292
180°	356°	9·929	145·9563
189°	372·2°	12·125	178·2375
199°	390·2°	15·062	221·4114
213°	415·4°	19·997	293·9559
225°	437°	25·125	369·3375
239°	462·2°	27·534	404·7498

No rational law for vapour tension has yet been found, but the experiments indicate generally that the tension increases at a greater rate than the heat intensity, and the statement of this increase has been placed in the form of an empirical formula.

Dynamic Theory of Heat.—The various phenomena of heat which have been so far sketched, and its effects upon the state of matter have been but a record of results which, to a great extent at least, have been known to science in the main for a long period. The statement and proof that heat is a measurable mechanical quantity is of comparatively recent date; and since this has been proved the science of heat has made considerable progress, and the previously observed phenomena, and their bearing on physical science generally, has been better understood.

In the last year of last century DAVY rubbed two pieces of ice together until both were melted, and then to prove that the heat which melted the ice was not absorbed from the surrounding atmosphere, but was the result of the friction, he caused two pieces of metal to rub together in a vacuum, the apparatus being supported on a block of ice, having a reservoir of ice-cold water on its surface; and as the water was neither frozen nor the ice melted, he proved that the heat developed came neither from the ice nor the air, and was therefore the result of the friction. Later on he laid down the following enunciation of a law, that the cause of the phenomenon of heat is motion, and that the laws which govern it are the laws of motion.

In the same year Count RUMFORD was struck with the heat which was produced in the boring of brass cannon at the arsenal at Munich, and could not satisfy himself that the heat was a material substance, but came to the conclusion that it was motion; and when, after a long-continued action of his boring-tool, he succeeded in not only heating water, but actually making it boil, he stated emphatically that it was motion.

The deduction of both these philosphers, that heat *is* motion, appears to be barely warranted, and both seem to have performed a mental elimination of the force that was at work producing the motion. The correct statement of the result of the experiments would appear to be that heat is a measurable quantity, and may be measured by the motion which it produces, as far as *motion* is concerned, or that heat can produce mechanical effect, and that mechanical effect can produce heat in measurable quantity, so far as regards *work*.

A quarter of a century elapsed before the next step in the present theory of heat was made, in 1824, by Carnot, whose law is stated by Sir Wm. Thomson thus ("Edinburgh Transactions," 1849, vol. xxi.) :—That the ratio of the greatest possible work performed by a heat engine, to the whole heat expended, is a function of the two limits of temperature between which an engine works, and not of the nature of the substance employed. Hence heat "does work by being let down from a higher to a lower temperature." Carnot constructed an engine of maximum effect, or reversible engine, in which the working substance is brought to exactly the same condition at the termination of a cycle of operations as at the commencement. This will be further referred to in the sequel.

So far no attempt had been made to test experimentally the mechanical equivalent of heat; it may be deduced now with some degree of accuracy from the results of Rumford's experiments, but it was not done, and this most important constant in thermodynamics was not studied until the year 1842. On this subject the following quotation from the introduction to Rankine's "Steam Engine," already referred to, may be made :—

"The phenomena of the development of heat by the friction of a fluid possesses peculiar advantages as a means of ascertaining the relations between heat and mechanical power, owing to the simplicity of the action which takes place; for at the end of the process the fluid is left exactly in the same condition as it was at the beginning, so that the evolution of a certain amount of heat is the sole effect produced; and this being compared with the mechanical power expended in agitating the fluid, exhibits in the most simple, direct, accurate, and satisfactory manner possible the relation between heat and mechanical power. The idea of subjecting this phenomenon to experimental measurement appears to have been first put in practice independently by Mayer in 1842, and Joule in 1843. The numerical results at first obtained were, as was to be expected in a new kind of experiment, somewhat rough and inexact; but by long perseverance Joule increased the exactitude of his methods of experimenting, until he succeeded in ascertaining, by experiments on the friction of water, oil, mercury, air, and other substances, to the accuracy of $\frac{1}{300}$ of its amount, if not more closely still, the *mechanical equivalent of a unit of heat*; that is, *the number of foot-pounds of mechanical energy which must be expended in order to raise the temperature of one pound of water by one degree.* For Fahrenheit's degree, that quantity is 772 foot-pounds; for the Centigrade degree, $\frac{9}{5} \times 772 = 1389{\cdot}6$ foot-pounds (*Philosophical Transactions*, 1850). This, the most important numerical constant in molecular physics, has been styled by other writers on the subject 'Joule's Equivalent,' in order that the name of its discoverer may be perpetuated by connection with the most imperishable of memorials—a truth. Joule, at the same time, proved by experiment the law which had previously been only a matter of speculative theory with others: that not only heat and motive power, but all other kinds of physical energy, such as chemical action, electricity, and magnetism, are convertible and equivalent; that is to say, that any one of those kinds of energy may, by its expenditure, be made the means of developing any other in certain definite proportions. Meanwhile, partly through a theoretical anticipation of this law, and partly through the influence of the hypothesis of *molecular motions* as applied to heat, the formation of a systematic theory of the relations between heat and motive power advanced. Helmholtz and Waterston may be referred to as having aided that progress. The investigations of the Count de Pambour on the theory of the steam engine, although not involving the discovery of any principle in thermodynamics properly speaking, were conducive to the progress of that science by pointing out the proper mode of applying mechanical principles to the expansive action of an elastic fluid."

Throughout this historical reference to the modern science of thermodynamics, investigators, wide apart, appear to have arrived at similar results at almost the same time. Rumford and Davy, Mayer and Joule; so again in the next advance. The general equation of thermodynamics, which expresses the relations between heat and mechanical energy under all circumstances, was arrived at independently and by different methods, in 1849, by Professors Rankine and Clausius. Both these writers have depended upon certain hypotheses, by means of which they have arrived at the anticipation of certain results, afterwards proved experimentally. In referring to his own hypothesis, Rankine says :—In thermodanamics, as well as in other branches of molecular physics, the laws of phenomena have to a certain extent been anticipated, and their investigation facilitated, by the aid of hypotheses as to occult molecular structures and motions with which such phenomena are assumed to be connected. The hypothesis which has answered that purpose in the case of thermodynamics is called that of "molecular vortices," or otherwise, the "centrifugal theory of elasticity." (On this subject, see the *Edinburgh Philosophical Journal*, 1849; *Edinburgh Transactions*, vol. xx.; and *Philosophical Magazine*, *passim*, especially for December, 1851, and November and December, 1855.)

The above is a short sketch of the progress that has been made in the dynamics of heat; some portions of the subject which have been only referred to will require further treatment in considering thermodynamics.

The Science of Energy.—This science, of which heat only forms a particular branch, will now be shortly referred to. Energy has been defined as a capacity to effect changes, or for performing work, and is expressed by the product of a force into a space.

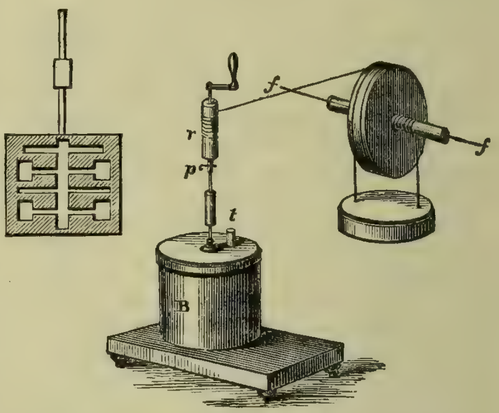
Energy may be divided into two classes, potential and actual or kinetic. Potential energy may be defined as the product of an effort into the distance through which it is capable of activity. Thus, a weight of 1 lb. raised a distance of 100 feet has the potential energy of 100 foot-lbs., as that is the amount of the work it is capable of performing in its descent. This potential energy is due to the body having had already done upon it a certain amount of work, or having been produced in a certain condition, in which it has an advantage with regard to the attraction of gravitation over other bodies of an equal mass at a lower level. Another form of potential energy is a mass of heated steam in a boiler which is at a certain higher temperature, and therefore in a position of advantage with reference to a condenser at a lower temperature, and can therefore perform a certain amount of work due to this intensity of heat in being let down to the lower temperature. A reservoir of water at a higher level than a water-wheel, which it can be employed to turn, is another form of potential energy. Actual or kinetic energy is the energy which a body has in virtue of its being in a state of motion, and is the work which it is capable of doing against a retarding resistance before being brought to a state of rest, and is equal to the energy which must be exerted on the body to bring it from a state of rest to its actual velocity. It is the product of the weight of a body into the height from which it must fall in order to acquire its velocity. Actual energy is only relative, and it is the motion of a body relatively to some other body or bodies upon which it is capable of performing work that has to be considered in taking its actual or kinetic energy. If, for example, it is wished to determine how many turns a wheel of a locomotive engine, rotating with a given velocity, would make before being stopped by the friction of the bearings only, supposing it to be lifted out of contact with the rails, the actual energy of that wheel is to be taken relatively to the frame of the engine to which the bearings are attached, and is simply the actual energy due to the rotation. But if, on the other hand, the wheel be supposed to be detached from the engine, and it is inquired how high it will ascend up a perfectly smooth inclined plane before being stopped by the attraction of the earth, then the actual energy relatively to the earth is to be taken; that is to say, to the energy of rotation already mentioned is to be added the energy due to translation or forward motion of the wheel along with the axis.

There are three subjects which bear upon energy; the first is the law of the conservation of energy, which asserts that energy is indestructible, and that it only changes its form. The second portion deals with the transformation of the different kinds of energy, the laws regulating which, although considerably advanced by Joule, Rankine, Clausius, Thomson, Helmholtz, and Hirn, are still only imperfectly known. The third branch, referring to the dissipation of energy, has been particularly advanced by Sir W. Thomson.

We shall now proceed to the two laws of thermodynamics.

The first law of thermodynamics gives the relation between heat and mechanical effect. It has been mainly if not entirely established by the experimental investigations of Joule, of one of which we proceed to give a description, that is, his determination by means of fluid friction. These are the experiments already referred to, and were carried on from 1842 to 1849. The apparatus employed is shown in the accompanying sketch of Joule's apparatus. It consists of two principal portions, a box containing water, in which a paddle, by means of its rotation, produces an increase of temperature through the friction of its solid particles with the fluid particles of the water, and an arrangement by which a descending weight produces a rapid motion, and the work which is formed into heat; the weight is attached to a pulley supported by friction rollers. There are eight sets of paddles revolving between four stationary vanes, thus preventing the whirling of the liquid. The peg, *p*, is withdrawn when it is wished to wind up the weight without moving the paddles. The heat produced in the axles of the pulleys was allowed for. A thermometer gives the temperature of the water.

Fig. 8.



The radiation and conduction of heat were prevented as far as possible, and measured when existing, and the heat equivalent of the work was thus deduced as 772 foot-lbs. of energy required to raise the temperature of 1 lb. of water 1° Fahr., or 1390 foot-lbs. to raise it 1° C. This is equivalent to 424 kilogrammétres required to raise 1 kilogramme of water 1° C., the French unit of heat.

The above is the value of the mechanical equivalent of heat usually accepted in this country, and known as Joule's equivalent: it is not, however, so universally accepted on the Continent, where some recent deductions have made it somewhat larger.

Various other methods have been employed for the purpose of measuring the mechanical equivalent for heat. Joule caused a rotating metallic disk to be brought between the poles of a powerful electromagnet; the energy of rotation is almost immediately stopped, and the temperature of the disk will have increased, the heat being the equivalent of the energy of rotation. Various experimentalists have employed different methods to obtain the value of this important constant; the names of these and the various methods they have employed is given in the following table which has been published by the Physical Society of Berlin; the values marked (*) are of recent investigation.

TABLE PUBLISHED BY THE PHYSICAL SOCIETY OF BERLIN.

Method of Determination and Experimental Data.	Observers.	Date.	Mechanical Equivalent.	
			E in Kilogrammetres.	J in Foot-Lbs.
I. BY CALCULATION.				
(A.) From the difference of the heat capacity of gases.				
1. Atmospheric air,........................	Mayer.	1842	365	657
2. "	Holtzmann.	1845	374	673·2
3.* "	Clausius.	1850	370	666 *
4. Atmospheric air—				
$d = 1{\cdot}000$; $\alpha = 0{\cdot}003665$; $C_p = 0{\cdot}2377$....	Regnault.			
$\gamma = 1{\cdot}348$	Clément Desormes.	1850	480·1	864·18
$\gamma = 1{\cdot}375$	Gay Lussac & Welter.	"	452·6	814·68
$\gamma = 1{\cdot}4172$....	Dulong.	"	419	754·2
$\gamma = 1{\cdot}4078$....	Moll & Van-Beck.	"	426	766 8
5. Oxygen—				
$d = 1{\cdot}1056$; $\alpha = 0{\cdot}00367$; $C_p = 0{\cdot}2412$....	Regnault.			
$\gamma = 1{\cdot}4158$....	Dulong.	"	414·3	745·74
$\gamma = 1{\cdot}3998$....	Van Rees.	"	425·7	766·26
6. Nitrogen—				
$d = 0{\cdot}9713$; $\alpha = 0{\cdot}00367$; $C_p = 0{\cdot}237$	Regnault.			
$\gamma = 1.428$	Van Rees.	"	431 3	560·34
7. Hydrogen—				
$d = 0{\cdot}0692$; $\alpha = 0{\cdot}003665$; $C_p = 0\ 2356$....	Regnault.			
$\gamma = 1{\cdot}4127$...	Dulong.	"	425·3	765·54
8. Carbonic oxide—				
$d = 0{\cdot}9674$; $\alpha = 0{\cdot}003669$; $C_p = 0{\cdot}2399$....	Regnault.			
$\gamma = 1{\cdot}4142$....	Dulong.	"	417	750·6
$\gamma = 1{\cdot}4092$....	Masson.	"	420·7	757·26
9. Carbonic acid—				
$d = 1{\cdot}529$; $\alpha = 0{\cdot}00371$; $C_p = 0{\cdot}3308$....	Regnault.			
$\gamma = 1{\cdot}3382$....	Dulong.	"	354·6	638·28
$\gamma = 1{\cdot}2867$....	Masson.	"	402·3	724·14
10. Nitrous oxide—				
$d = 1{\cdot}525$; $\alpha = 0{\cdot}003719$; $C_p = 0{\cdot}3413$....	Regnault.			
$\gamma = 1{\cdot}3366$....	Dulong.	"	345·6	622·08
$\gamma = 1{\cdot}2795$....	Masson.	"	399	718·2
11. Sulphuric acid—				
$d = 2{\cdot}247$; $\alpha = 0{\cdot}003903$; $C_p = 0{\cdot}3489$....	Regnault.			
$\gamma = 1{\cdot}2522$....	Masson.	"	423·8	762·84
We omit the other gases given by Bosscha, because their co-efficient of expansion has not been directly determined.				
(B.) From the theory of vapours.				
12. Steam—				
Clausius, by means of Carnot's theory,.......	Clausius.	1850	421	757·8
Reech, after Carnot's theory,...............	Reech.	1858	434·9	782 82
Seguin, without stating his method,.........	Seguin.	"	449	808·2
(C.) From the expansion and elasticity of solid bodies.				
13. Kupffer, the expansion and elasticity of metals,..............................	Kupffer.	1852	404	727·2
II. FROM DIRECT OBSERVATION.				
1. Compression of air,........................	Joule.	1845	443·8	798·84
2. Expansion of air,...........................	"	"	437·8	788·04
3. Friction of water in narrow tubes,..........	"	1843	422·4	760·32
4. Friction of water by a paddle—				
First experiments,........................	"	1845	488·3	878·94
Other experiments,........................	"	1847	428·9	772·02
Latest experiments, very carefully executed,	"	1850	423·9	763·02
5. Friction of paddle in mercury,..............	"	"	424 7	764·46
6. Friction of an iron paddle in mercury, ...	"	"	426·2	767·16
7. Direct friction of metals—				
Mean value of the first series of experiments,	Hirn.	1857	371·6	668·88
New experiments, ...	"	1858	400 and 450	720 and 810
8. The boring of metals,......................	"	"	425	765
9. Determination of heat due to friction by means of the mercury calorimeter,........	Favre.	"	413·2	743·76
10. Experiments upon the steam engine,.......	Hirn.	1857	413	743·4
11. Heating by the magneto-electric current,...	Joule.	1843	462·5	832·15
12. Diminution of the production of heat in the electric circuit when the current produces work,..................................	"	"	442·2	795 96
13. Ditto, ...	Favre.	1857	443	797·4

[*] These determinations depend upon the value $C_p = 0{\cdot}2669$ given by Delaroche and Berard for the heat capacity of air, and on the ratio 1·421 indicated by Dulong. In the following calculation the weight of a cubic metre of air at zero C., and 760 mm. has been taken at 1·293 kilo., the value given by M. Regnault.

TABLE PUBLISHED BY THE PHYSICAL SOCIETY OF BERLIN—(*Continued.*)

Method of Determination and Experimental Data.	Observers.	Date.	Mechanical Equivalent.	
			E in Kilogrammetres.	J in Foot-Lbs.
14. Heat due to electric currents; the electric chemical equivalent of water = 0·009376 absolute resistance,.....................	Weber.	1857	432·1	777·78
Development of heat by the action of zinc on sulphate of copper,.....................	Favre and Silbermann.	"	432·1	777·78
Measure of the electro-motive force of a Daniell's pile, from the absolute measure = 10258 × 10^7,.....................	Bosscha.	"	432·1	777·78
15. Heat developed in Daniell's pile,..........	Joule.	"	419·5	755·1
The electro motive force of Daniell's pile,...	Bosscha.	"	419·5	755·1
16. Measure of the absolute resistance,........	Weber.	"	—	—
Heat developed by the absolute unit of an electric current, in a circuit of which the resistance is one,.....................	Quintus Icilius.	"	399·7	719 46
17. Heating by the magneto-electric current,...	Le Roux.	"	462·2	832
To these values given by the Physical Society of Berlin are added those found by M. Hirn in the years 1860 and 1861.				
1. Friction of various liquids in his dynamometer. This machine expends between 300 and 350 kilos. of work per second.				
Rape-seed oil, sperm oil, whale oil, paraffin oil, benzine, and water,..................	Hirn.	1857	400 to 432	720 to 777·6
Flow of water under a very great pressure in a narrow tube,.........................	"	"	432	777·6
2. Crushing of lead,.........................	"	"	425	765
3. Numerous experiments on the steam engine,	"	"	420 to 432	756 to 777·6
4. Value calculated from the volumes of superheated steam,.........................	"	"	432	777·6
5. From the expansion of air in the thermomanometer. Maximum impossible value,	"	"	440	792
From the *Bulletin de la Société Scientifique Industrielle de Marseille*, No. 3, 1874, pp. 133–143.				
Gyroscope revolving between the poles of an electro-magnet with copper,..............	Jules Violle.	—	439·05	790·3
With lead,................................	"	—	441·05	793·9
" brass,................................	"	—	439·6	791·4
" aluminium,............................	"	—	438·72	789·7

Second Law of Thermodynamics.—We now proceed to a statement of the second law of thermodynamics: it is proposed to follow the exposition of Sir WILLIAM THOMSON. We have mentioned CARNOT as being the first to propose the idea of a reversible engine, which we shall now proceed to follow through a cycle of changes. Any cycle is reversible when the working substance is throughout in contact either with bodies at its own temperature or with non-conducting substances, and further, it is abundantly proved that a reversible engine will produce as much effect as can be produced by any engine working between the same temperatures.

Assume a mass of substance of volume v, pressure p, and temperature t, which will pass through a cycle of operations represented in the following figure (and about to be described), in which pressures are represented by the lines parallel to OX, drawn from and above the line OY, whilst volumes are represented along OY.

Let the volume v be represented by Oe, and the pressure p by ae.

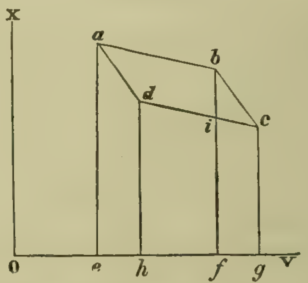
First operation. Let the substance expand by the supply of heat at the constant temperature t, its new volume being Of, and pressure bf, less than ae.

Second operation. Let it further expand in a non-conducting vessel, so that it can neither absorb nor emit heat, whilst its temperature falls through an infinitely small quantity τ, its new temperature being t-τ, the volume being Og and the pressure gc.

Third operation. Let it be compressed at the temperature t-τ, to such volume Oh, and pressure dh, that when,

Fourth operation, it is further compressed in the

Fig. 9.



non-conducting vessel so as neither to absorb nor emit heat, it returns to its original volume, temperature, and pressure. As the operations 1 and 3 and 2 and 4 are exactly reverse, and are supposed to be infinitely small, the figure $abcd$ represents the whole work done by the body, and is a parallelogram.

If the cycle of operation is worked backwards, starting from the lower temperature, $t-\tau$, the closed parallelogram, *abcd*, will represent the work done upon the body. In both cases the heat is proportional to the change of volume, *ef*, and may be represented by the product of a quantity, M, into *ef* or M*ef*, and represents in the first case heat drawn from the source of higher temperature, and in the second, heat returned to that of the lower.

Whatever substance we employ, if the range of temperature (*i.e.*, the initial and final temperature) remains constant, the ratio of work done to the heat drawn from the source remains constant, or area $\frac{abcd}{M.ef}$ is constant.

But in the parallelogram, *bi* denotes the change of pressure of the working substance of constant volume due to the change of temperature, so that

$$bi = \frac{dp}{dt}\tau; \text{ hence, area } \frac{abcd}{Mef} = \frac{bi.ef}{Mef} = \frac{\frac{dp}{dt}\tau}{M}$$

In this ratio, as τ may always be arranged to be the same, it may be dispensed with, or $\frac{\frac{dp}{dt}}{M}$ is a function of the temperature, and does not vary with the nature of the substance.

Let us now consider the working substance to be a perfect gas, then the heat absorbed in expansion at constant temperature is the exact equivalent of the work done, the mechanical equivalent of which is $J\,M\,dv$, in which J is JOULE'S equivalent. On the other hand, the mechanical equivalent of the work is the product of the pressure into the change of volume, or $pdv = P\,(1 + \alpha t)\,dv$, in which P is the pressure at zero C., and α is the coefficient of expansion of a perfect gas; and it follows that $\frac{dp}{dt} = P\alpha$. Equating these values of the work—

$$J\,M\,dv = P\,(1 + \alpha t)\,dv \text{ and } \frac{\frac{dp}{dt}}{M} = \frac{J\,\alpha}{1 + \alpha b.}$$

Again, the absolute temperature is $\frac{1}{\alpha} + t^\circ$, or

$$\frac{1 + \alpha t^\circ}{\alpha} \text{ therefore } \frac{\frac{dt}{dp}}{M} = \frac{J}{\text{absolute temperature.}}$$

which is the form of this function as given in terms of absolute temperature. It would be beyond the scope of this article to trace the subject further.

Combustion.—Allusion has already been made in the preceding pages to various sources of heat; but those which will fall to be considered in connection with the subject of this article, are certain material substances which, in the act of undergoing chemical changes, yield both heat and light. This process is termed combustion. At one period, and among the disciples of LAVOISIER in particular, oxidation and combustion were considered synonymous. It is true that in most cases of combustion, as in that of a common fire, the effect is produced by the oxidation of the materials; but cases of combustion occur when no oxygen is present. Antimony, for example, burns when heated in an atmosphere of chlorine; copper or iron, when heated with sulphur; potassium, with cyanogen, &c. These instances demonstrate the fact that oxygen is not essential to combustion, although it is eminently capable of supporting it; and being so extensively disseminated in the atmosphere, it acts as the almost universal agent in this phenomenon.

Though the term *combustion* is generally limited to cases of chemical combination accompanied with heat and light, yet it is sometimes extended to express the union of bodies with oxygen effected at a low temperature. Iron, for example, when exposed to moist air, undergoes a change in oxidizing, whereby its metallic characteristics disappear; the constituents of the blood are modified by a similar chemical process, but in neither case is light produced; and if heat is generated in the former, it is quite inappreciable even by delicate instruments. In both cases, however, the effect produced is sometimes characterized as a process of *eremacausis* or *slow combustion.*

In cases of vivid, as distinguished from slow combustion, the heat and light seem to be evolved from the solid, liquid, or gaseous bodies which burn, and hence they are termed *combustibles*, while the gaseous atmosphere in which they are involved, such as oxygen or chlorine, is termed the *supporter of combustion.* It is evident, however, that this distinction is radically faulty, inasmuch as the phenomena of light and heat may be regarded as proceeding either from the one or the other. The combustible, usually so called, may be represented as supporting the combustion of the atmosphere in which it is enveloped, and the latter, regarded in this view, becomes the real combustible. In strictly philosophical language, the combustion proceeds from the combination, which can only take place at the point of contact; and therefore it is quite impossible to say to which of the bodies so combining is due the evolution of heat and light, or, in other words, which is the combustible and which the supporter of combustion.

We shall, however, consider combustion only as rapid, and the combination of different fuels with the oxygen of the atmosphere. In ordinary fuel the chief combustible constituents are carbon and hydrogen. Sulphur is another combustible, but it is found only in small quantities, and in most metallurgical operations in which fuels are employed its absence is preferred. The following quotation from Dr. SIEMENS' lecture on Fuel, delivered to the operative classes at Bradford, on behalf of the British Association, places clearly before the mind what is available on the earth as fuel.

"Fuel, then, in the ordinary acceptation of the term, is carbonaceous matter, which may be in the solid, the liquid, or in the gaseous condition, and which, in combining with oxygen, gives rise to the phenomenon of heat. Commonly speaking, this development of heat is accompanied by flame, because the substance produced in combustion is gaseous. In burning coal, for instance, on a fire grate, the oxygen of the atmosphere enters into combination with the solid carbon of the coal and produces carbonic acid, a gas which enters the atmosphere, of which it forms a necessary constituent, since without it the growth of trees and other plants would be impossible. But combustion is not necessarily accompanied by flame, or even by a display of intense heat. The metal magnesium burns with a great display of light and heat, but without flame, because the product of combustion is not a gas but a solid, viz., oxide of magnesium. Again, metallic iron, if in a finely divided state, ignites when exposed to the atmosphere, giving rise to the phenomena of heat and light without flame, because the result of combustion is iron oxide or rust; but the same iron, if presented to the atmosphere—more especially to a damp atmosphere—in a solid condition, does not ignite, but is nevertheless gradually converted into metallic oxide or rust as before.

"Here, then, we have combination without the phenomena either of flame or light; but by careful experiment we should find that heat is nevertheless produced, and that the amount of heat so produced precisely equals that obtained more rapidly in exposing pulverulent iron to the action of oxygen. Only, in the latter case, the heat is developed by slow degrees, and is dispersed as soon as produced, whereas in the former the rate of production exceeds the rate of dispersion, and heat therefore accumulates to the extent of raising the mass to redness. It is evident from these experiments that we have to widen our conception, and call fuel '*any substance which is capable of entering into combination with another substance, and in so doing gives rise to the phenomenon of heat.*'

"In thus defining fuel, it might appear at first sight that we should find upon our earth a great variety, and an inexhaustible supply of substances that might be ranged under this head; but a closer investigation will soon reveal the fact, that its supply is, comparatively speaking, extremely limited.

"In looking at the solid crust of the earth, we find it to be composed for the most part of siliceous, calcareous, and magnesian rock; the former, silica, consisting of the metal silicon combined with oxygen, is not fuel, but rather a burnt substance which has parted with its heat of combustion ages ago; the second, limestone, being carbonate of lime, or the combination of two substances, viz., calcic oxide and carbonic acid, both of which are essentially products of combustion, the one of the metal calcium, and the other of carbon; and the third, magnesia, a combination of oxygen with the metal magnesium, and which, further combined with lime, constitutes dolomite rock, of which the Alps are mainly composed. All the commoner metals, such as iron, zinc, tin, aluminium, sodium, &c., we find in nature in an oxidized or burnt condition; and the only metallic substances that have resisted the intense oxidizing action that must have prevailed at one period of the earth's creation are the so-called precious metals, gold, platinum, iridium, and to some extent also silver and copper. Excepting these, coal alone presents itself as carbon and hydrogen in an unoxidized condition. But what about the oceans of water, which have occasionally been cited as representing a vast store of heat-producing power ready for our use when coal shall be exhausted. Not many months ago, indeed, on the occasion of a water-gas company being formed, statements to this effect could be seen in some of our leading papers. Nothing, however, could be more fallacious. When hydrogen burns, doubtless a great development of heat ensues, but water is already the result of this combustion (which took place upon our globe before the ocean was formed), and the separation of these two substances would take precisely the same amount of heat as was originally produced in their combustion. It will thus be seen that both the solid and fluid constituents of our earth, with the exception of coal, of naphtha (which is a mere modification of coal), and the precious metals, are products of combustion, and therefore the very reverse of fuel."

As chemical combustion depends upon certain proportions of the combining substances, the number of pounds of air required to supply the oxygen for any definite fuel is definite, and depends upon the composition of the fuel, and is given by the following formula—

$$A = 12C + 36\left(H - \frac{O}{8}\right),$$

in which C, H, and O represent the carbon, hydrogen, and oxygen respectively found on analysis in the fuel, and A the number of pounds of air required. As a practical rule 12 lbs. of air per pound of fuel for coal and coke is generally considered to be sufficiently approximate. An additional supply of air is required for dilution, but the smaller the pieces of fuel the less air is required for this purpose. Insufficient air causes smoke, or the production of carbonic oxide, according to the nature of the fuel, the presence of the latter being known by the purple flame in the fire. Too much air represents loss through the excess weight of air which is raised in temperature.

For success in burning fuel, it is required to have a properly constructed furnace, when the air sufficient for complete combustion will pass through the grate bars, and the fireman will only require to spread the fuel evenly and in thin layers over the surface of the burning fuel. This applies to all fuel in which there is not an excess of hydrocarbons; when such is the case, a dead plate is used consisting of a plate at the mouth of the furnace, where the hydrocarbons are distilled, and then the coke is pushed forward and thrown over the fuel.

The rate of combustion of fuel depends on the draught or the quantity of air supplied to the fuel in a unit of time, which is expressed either in weight or volume of the products of combustion, or by means of the velocity of the current. RANKINE lays down as a practical rule, that "to insure the best possible draught through a given chimney, the temperature of the hot gas in the chimney should be nearly, but not quite, sufficient to melt lead." A certain amount of fuel must always be expended in order to produce a draught, and hence in the construction of furnaces questions arise as to whether greater economy will be produced by the use of a natural chimney draught, or by means of a blast pipe, or fan, or other blowing machine.

The available heat of combustion has been defined as that portion of the total heat of combustion which is communicated to the body to heat which the fuel is burned, and the efficiency of a furnace is the ratio of the available heat to the total heat of combustion. It must be particularly remembered that the combustion of different fuels in the same furnace cannot be considered as a measure of the combustible value of such fuels, as the same furnace is more suitable for one fuel than another, and for one mode of firing than another.

The available heat falls short of the total heat of combustion from various causes clearly stated in the following extract from Professor Rankine's "Steam Engine."

"I. *Waste of Unburnt Fuel in the Solid State.*—This generally arises from brittleness of the fuel, combined with want of care in the stoker, by which causes the fuel is made to fall into small pieces, which escape between the grate bars into the ash pit.

"Many of the most valuable kinds of coal, such as the dry steam coals, are brittle. The waste of such coals in the solid state is to be prevented by the following means:—(1.) They are to be thrown evenly and uniformly over the fire with the shovel, so that there shall be no occasion to disturb them after they are first thrown in. (2.) The fire is not to be stirred from above; and the grate bars are to be cleared when required by a hook or slice from below. (3.) The ashes are to be riddled from time to time, and the small coal or cinders contained amongst them thrown upon the fires.

"It is impossible to estimate the greatest amount of this kind of waste which may arise from careless firing; but the amount which is unavoidable with good firing has in some cases been ascertained by experiment, and found to range from nothing up to about 2½ per cent.

"II. *The Waste of Unburnt Fuel in the Gaseous and Smoky States*, the means of preventing which is by a sufficient supply and proper distribution of air.

"The greatest probable amount of that waste, when the absence of any provision for introducing air to burn the inflammable gases is combined with bad firing, may be estimated by taking the proportion in which the total heat of combustion of the coke or fixed carbon contained in 1 lb. of coal is less than the total heat of combustion of all the constituents of 1 lb. of the coal.

"When the firing is conducted with care, but the supply of air insufficient, the waste may be estimated by treating the hydrogen as ineffective; that is, by taking the proportion in which the heat due to the *whole* of the carbon in the coal is less than the heat due to the carbon and to the hydrogen in excess of that required to form water with the oxygen in the coal. This method of calculation proceeds on the supposition that the whole of the hydrocarbons are decomposed into carbon and hydrogen by the heat, that the carbon is completely burnt, and that the hydrogen escapes unburnt. That supposition appears to represent with an approach to accuracy the state of things in good ordinary steam boiler furnaces which have no special provision for distributing air amongst the inflammable gases; for the result of experience with such furnaces is, that the relative values of coals consumed in them are nearly proportional to the quantities of carbon contained in those coals.

"It appears, then, that there are *two degrees* of waste from imperfect combustion of the gas and smoke from *one pound* of bituminous coal, which, as reduced to *equivalent weights of carbon*, may be expressed as follows:—

	Waste reduced to carbon.
(1.) Insufficient air, but good firing, the surplus hydrogen wasted,.....	$4{\cdot}28\left(H - \frac{O}{8}\right)$;
(2.) Very insufficient air, and bad firing; all the hydrocarbons wasted. If the hydrogen and carbon in these are combined in the same proportion as in marsh gas (H_2C); then for every lb. of hydrogen wasted, 3 lbs. of carbon are wasted also; giving as the total waste reduced to carbon,......................	$7{\cdot}28\left(H - \frac{O}{8}\right)$;
If the hydrogen and carbon are combined in the same proportion as in olefiant gas (H_2C_2), then for every lb. of hydrogen wasted, 6 lbs. of carbon are wasted also; giving as the total waste reduced to carbon,	$10{\cdot}28\left(H - \frac{O}{8}\right)$;
And for intermediate proportions, intermediate quantities are wasted.	

"III.—*Waste by External Radiation and Conduction.*—The waste by direct radiation from burning coal through an open fire door may be approximately estimated by assuming, in the first place, the heat directly radiated from the fuel to be one half of the total heat of combustion; next, conceiving the surface of the burning mass to be divided into several small equal parts, from each of which an equal share of the heat radiates; then, finding what fraction of the surface of a sphere described about one of those parts is subtended by the opening through which the radiation takes place, and multiplying the share of heat radiated from the part of the fuel in question by that fraction; and lastly, adding together the products so found for the several parts of the burning fuel. The loss by conduction through the solid boundaries of the furnace may be estimated from their area, their material, their thickness, their thermal resistance, and the difference of the temperatures within and without the furnace. In well planned and well constructed furnaces, however, those losses of heat should be practically inappreciable.

"IV. *Waste or Loss of Heat in the Hot Gas which Escapes by the Chimney.*—Considering that the temperature of the fire, in a furnace with a draught produced by a chimney, and supplied with 24 lbs. of air per lb. of fuel, is about 2400° Fahr. above the temperature of the external air, and that the temperature of the hot gas in the chimney, in order to produce the best possible draught, should be about 600° above the temperature of the external air, it appears that under no circumstances can it be necessary to expend more than *one-fourth* of the total heat of combustion for the purpose of producing a draught by means of a chimney. By making the chimney of large enough dimensions as compared with the grate, a much less expenditure of heat than this may be made to produce a draught sufficient for the rate of combustion in the furnace.

"When the draught is produced by means of a blast pipe, or of a blowing machine, no elevation of temperature above that of the external air is *necessary* in the chimney; therefore, furnaces in which the draught is so produced are capable of greater economy than those in which the draught is produced by means of a chimney.

"It appears further, as has already been stated, that with a forced draught there is less air required for dilution, consequently a higher temperature of the fire, consequently a more rapid conduction of heat through the heating surface, consequently a better economy of heat than there is with a chimney-draught."

Calorific Power of Fuel.—By this expression is meant the amount of heat developed by a specified weight of the combustible under consideration. The methods that have been employed for these determinations are various, and they will have our later consideration.

Several investigators have bestowed considerable attention upon the subject of the quantity of heat developed by the combustion of different substances. LAVOISIER, LAPLACE, and RUMFORD, were the first to enter this field, and the research has been prosecuted with increasing success by several others, down to the recent investigations of FAVRE and SILBERMANN, DESPRETZ, DULONG, and ANDREWS. The principle upon which one and all founded their experiments, was that of determining the effect produced upon a third body by the heat given out during the union of the combustible under examination with oxygen. Any of the effects of heat may be employed with this view, on the principle that equal weights of the same substance in the same condition, and affected in the same way, produce equal amounts of heat. For the measurement of heat effects we require a standard of comparison. We might employ, for instance, as the standard, the amount of heat required to melt an unit weight of ice at the freezing point, producing water at the freezing point. Or we might define a unit quantity of heat as that required to evaporate water at its boiling point, under ordinary atmospheric pressure, into steam of the same temperature and tension, and such units are actually in use and known as evaporation units. But the method which is in general use is to express quantities of heat in units of weight of water heated one degree, as in pounds of water heated one degree Fahr. (the British unit of heat), or in kilogrammes of water heated one degree Centigrade (the French unit of heat). The French unit of heat is known as a Calorie, and is equivalent to 3·96832 British units, which number is the ratio of the product of a kilogramme stated in pounds, multiplied by a degree Centigrade in equivalent Fahrenheit degrees to unity, and the reciprocal of this 0·251996 is the number of French units in a British heat unit. The heat which evaporates a pound of water at the boiling point under one atmosphere of pressure is 966·1 British units of heat, and that which evaporates one kilogramme of water is 536·7 French units of heat, which numbers are in the ratio of 9 : 5, or the relation of the Fahrenheit and Centigrade scale, as the heat which evaporates is stated as the equivalent of temperature raised.

We now proceed to a description of the methods employed. The apparatus employed by RUMFORD consisted of a vessel of thin sheet copper, the base, top, and sides being rectangular in section, and the ends square. It inclosed a worm of three horizontal coils. One end of the worm was secured into the bottom near one of its square ends, and the other into the top near the other. A funnel-shaped mouthpiece was fitted to the lower opening, and beneath and within this was the substance burned whose calorific power was sought; the resulting current of air heated the coil, and water then passed to the other end, where it was connected to a similar vessel, similar to the first, to test whether all the heat was absorbed in the first, which was found to be the case. To avoid loss by radiation, the temperature of the water was lowered a fixed number of degrees below that of the air, and the combustion was continued until the water was raised the same number of degrees above the atmospheric temperature; to prevent loss by conduction the instrument was suspended on slender wooden supports.

The data required for the use of this apparatus are—n, the weight of substance burnt; w, the weight of water; c, the weight of copper of vessel; s, the specific heat of copper; t and t', initial and final temperature of water.

The following formula will express the calorific power of the substance tested. Let x represent the amount of heat produced by the combustion of unit weight of any substance in atmospheric air, then—

$$nx = (t' - t)\,(w + cs)$$

$$\text{then } x = \frac{(t' - t)\,(w + cs)}{n}$$

In this equation the quantity cs is required as the equivalent weight of water which would have been raised a certain number of degrees had the copper of the vessel not absorbed the heat. The glass of the thermometer employed, with its contained mercury, also absorbed a certain quantity of heat, but this was not allowed for in RUMFORD's experiments.

The apparatus employed by ANDREWS is shown in Fig. 10. If the substances to be experimented upon were gaseous, and the products of combustion were gaseous, the gases were mixed in proper proportion and introduced into a cylindrical vessel of thin sheet copper, *a*, Fig. 10. This was closed above by a screw and had a hole for the admission of a cork with a silver wire, *b*, which was connected to a second silver wire soldered to the screw by means of a thin platinum wire within the vessel. By these means the gaseous mixture could be detonated with the aid of a battery. The copper vessel was placed in a larger vessel, *c*, containing a known weight of water. This was suspended in a cylinder, *d*, having a movable cover, and inclosed in an outer cylinder, *e*, which was arranged to rotate upon its shorter axis, in order to bring every part of the apparatus to a uniform temperature, whose initial temperature was read off to ·02 of a degree Centigrade. The gases were then exploded. The outer vessel was closed with a cork and caused to rotate for thirty-five seconds, when the thermometer was again introduced. After this observation the apparatus was again rotated for thirty-five seconds and the loss of temperature noted, in order to calculate the cooling effect of the atmosphere during the experiment, which was found not to exceed ·0025 of the total heat set free. A modified form of this apparatus was employed for solid bodies ignited in oxygen.

Fig. 10.

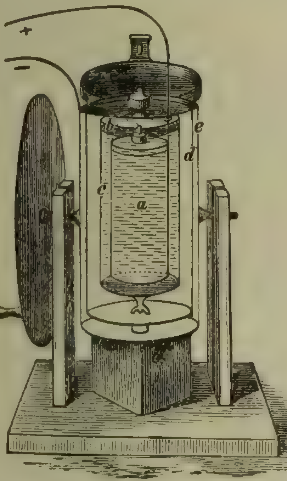
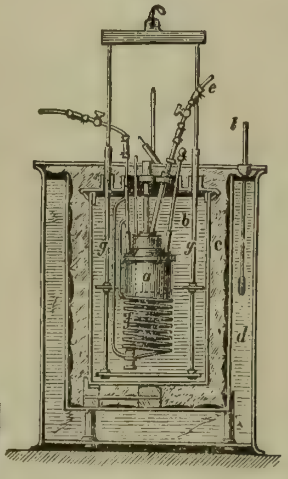


Fig. 11.



The experiments of Favre and Silbermann were performed in the apparatus shown in Fig. 11, by means of which a large series of experiments on the development of heat was made, on a larger scale even than those of Andrews, already referred to, the experimental results in the two cases being generally found to agree. Favre and Silbermann's apparatus consisted essentially of a vessel of brass gilt, *a*, in which the combustion took place: this vessel was placed in the calorimeter, *b*, of silvered copper containing water. The calorimeter was supported in another vessel, *c*, lined with swan's down, and was itself surrounded by a double cylinder, *d*, the annular space of which was filled with water. By this means the external influence of the atmosphere upon the internal temperature was found to be reduced to a minimum, and was easily measurable. When the combustions were performed in oxygen the gas was first dried and then allowed to flow into the combustion chamber by the tube, *e*, and the gases produced and the superfluous oxygen were made to traverse a spiral tube of thin copper, *f*, so as to assume the temperature of the water before quitting the apparatus Uniformity of temperature was produced by means of the agitator, *g*, *g*. The apparatus shown in the figure is the arrangement for burning carbon. Solid bodies were kindled by the introduction of live charcoal, liquids were burned in lamps having asbestos wicks, and gases were introduced by a jet previously inflamed. The weight of substance burnt was ascertained by weighing the products of combustion. The scale of the thermometers allowed of a reading of ·01 of a degree C.

Welter propounded the following law, namely, that all combustible bodies disengage the same amount of heat during their combination with the same weight of oxygen; or, in other words, that the heat developed was proportionate to the amount of oxygen assimilated during the combustion. Welter founded this theory upon the results of Laplace, Lavoisier, Despretz, Rumford, and others.

Berthier has founded a system of analysis upon this theory, by which the oxygen is estimated, and therefrom the heating power of the fuel deduced. It is easy and expeditious, and may, in the case of pure carbon, or of fuel consisting of carbon, without admixture of other reducing agents, be employed with advantage, and will be found to give correct results; if hydrogen is present, however, in the fuel, the result obtained would be erroneous. This appears from the consideration that 1 part by weight of hydrogen will reduce the same amount of oxide of lead as 3 parts of carbon; that is, hydrogen combines with exactly three times the quantity of oxygen that carbon takes up, and so from Welter's theory the heat developed should be three times greater when hydrogen is burned than when an equal quantity of carbon is consumed. In the following table, it will be seen that the calorific powers of hydrogen and carbon are as 34,462, and 8080. Hence the calorific power of 1 of hydrogen is to 3 of carbon approximately as 34 to 24. Hence the same weight of lead obtained by the reduction of the plumbous oxide, which would in the case of hydrogen indicate a calorific power of 34, would in the case of carbon represent 24 only, so that the process is not applicable to the determination of the calorific powers of fuels composed of variable quantities of hydrogen and carbon.

The method employed by Berthier is the following:—He mixes a weighed portion of the finely-powdered fuel with thirty to forty times its weight of oxide of lead—litharge—and introduces the compound into a fireclay crucible, pressing it gently, and covering the whole with a thick layer of the litharge. The crucible is then carefully closed, and placed on the fire, where it is gently heated till the whole of the carbon and hydrogen is burned. During this process the mass, being semifluid, is considerably distended by the carbonic acid and water, resulting from the combination of the elements of the fuel with the oxygen of the metallic oxide; towards the end of the operation, therefore, the fire should be quickened, and as soon as the crucible has attained a bright redness, it should be taken out, and its bottom struck gently against a stone or piece of iron, so as to cause the particles of reduced metal to accumulate and form a button. As soon as cold the crucible is broken, and the metal, coated with oxide of lead and slags from the ashes of the fuel, is abstracted. It is cleaned from the adhering impurities by a few blows of a hammer upon the anvil, and subsequent brushing, after which it is weighed. From the number thus found, the oxygen required for the combustion of the fuel is calculated, since it is derived from the oxide of lead—a definite compound of equivalent proportions of lead and oxygen. With pure carbon thirty-four and a half times the weight of the sample of metallic lead has been obtained. This amount of metal stands in a definite relation to the oxygen burned, and consequently to the heating power of the fuel also; for, supposing a certain weight of metal to be produced, the following ratio will give the heating power of the fuel: namely, as the metal obtained when operating with pure charcoal is to that reduced by the substance under experiment, so is the number expressing the units of heat of carbon to that of the fuel. For instance, the weight of metal obtained with pure charcoal is 34·5; allowing that with the subject of the experiment to be twenty; and taking Favre & Silberman's determination, or 8080, to represent the heating power of the charcoal, while x represents the unknown heating powers of the fuel; then,—

$$34·5 : 20 :: 8080 : x.$$

Or, the heating power $x = \frac{20 \times 8080}{34·5} = 4684$ nearly. When hydrogen is present without oxygen to combine with it, the experiment is inaccurate.

HEAT DEVELOPED DURING COMBUSTION IN OXYGEN.

Substance Burned.	Heat Units.		Grammes of water raised 1° C. by combination of 1 gramme of oxygen.	Pounds of water raised 1° Fahr. by combination of 1 pound of oxygen.	Calorific Equivalent.		Compound Formed.	Observers.
	Grammes of water raised 1° C. by 1 gramme of each substance.	Pounds of water raised 1° Fahr. by 1 pound of each substance.			Grammes of water raised 1° C. for 8 grammes (1 equivalent) of oxygen.	Pounds of water raised 1° Fahr. for 1 equivalent of oxygen.		
Hydrogen,..........	34,462	62,032	4,307	7,753	34,462	62,021	H_2O	Favre & Silbermann.
"	33,808	60,854	4,226	7,607	33,808	60,854	"	Andrews.
"	34,743	62,537	4,343	7,817	34,743	62,539	"	Dulong.
Carbon.............	8,080	14,544	3,030	5,454	24,240	43,632	CO_2	Favre & Silbermann.
"	7,900	14,220	2,962	5,332	23,696	42,653	"	Andrews.
"	7,912	14,242	2,967	5,341	23,736	42,725	"	Despretz.
Sulphur,............	2,220	3,996	2,220	3,996	17,760	31,968	SO_2	Favre & Silbermann.
"	2,307	4,153	2,307	4,153	18,456	33,221	"	Andrews.
"	2,601	4,682	2,601	4,682	20,808	37,454	"	Dulong.
Phosphorus,........	5,747	10,345	4,509	8,116	36,072	64,930	P_2O_5	Andrews.
"	5,669	10,204	4,391	7,909	35,148	63,274	"	Abria.
Zinc, ...	1,301	2,342	5,285	9,513	42,282	76,104	ZnO	"
"	1,298	2,336	5,273	9,491	42,185	75,931	"	Dulong.
Iron, ...	1,576	2,837	4,134	7,441	33,072	59,530	Fe_3O_4	Abria.
"	1,702	3,064	4,340	7,812	34,720	62,496	"	Dulong.
Cobalt,.............	1,080	1,944	3,995	7,191	31,960	57,528	?	"
Nickel,.............	1,006	1,811	3,723	6,701	29,784	53,611	NiO	"
Tin, ...	1,233	2,219	4,545	8,181	36,360	65,448	SnO_2	"
"	1,144	2,059	4,230	7,614	33,519	60,912	"	Abria.
Antimony,..........	961	1,730	5,875	10,575	47,000	84,600	Sb_2O_4	Dulong.
Copper,............	602	1,084	2,394	4,309	19,152	34,474	CuO	Abria.
"	632	1,138	2,512	4,522	20,096	36,173	"	Dulong.
Carbonic oxide,......	2,634	4,741	4,609	8,296	36,876	66,370	CO_2	"
"	2,431	4,376	4,258	7,664	34,034	61,315	"	Abria.
"	2,403	4,325	4,205	7,569	33,642	60,552	"	Favre & Silbermann.
Stannous oxide, ...	534	961	4,473	8,051	35,784	64,411	SnO_2	Dulong.
"	521	938	4,349	7,828	34,792	62,626	"	Abria.
Cupreous oxide,.....	256	461	2,288	4,118	18,304	32,947	CaO	"
"	244	439	2,185	3,933	17,480	31,464	"	Dulong.
Cyanogen,...........	5,195	9,351	4,221	7,598	33,768	60,782		"
Marsh gas,..........	13,063	23,513	3,266	5,879	26,128	47,030		Favre & Silbermann.
"	13,185	23,733	3,296	5,933	26,368	47,462		Dulong.
"	13,108	23,594	3,277	5,899	26,216	47,189		Abria.
Olefiant gas,........	11,942	21,496	3,483	6,269	27,864	50,155		Andrews.
"	11,858	21,344	3,458	6,224	27,664	49,795		Favre & Silbermann.
"	12,030	21,654	3,514	6,325	28,112	50,602		Dulong.
Alcohol,............	6,909	12,436	3,511	6,320	26,488	50,558		"
"	6,850	12,330	3,282	5,908	26,256	47,261		Andrews.
"	7,183	12,929	3,442	6,196	27,536	49,565		Favre & Silbermann.
Ether,..............	9,027	16,249	3,480	6,264	27,840	50,112		"
Oil of turpentine,....	10,852	19,534	3,294	5,929	26,352	47,434		"
Carbonic disulphide,..	3,401	6,122	2,692	4,846	21,536	38,765		"

With reference to the calorific power of carbon, as given in the above table, and also of some of the other substances, it will be noticed there is some difference between the results of the earlier experimentalists and the later ones. This is due to the fact, first stated by Dumas and Stas, that during the combustion of carbon, even in pure oxygen, there is always a certain amount of carbonic oxide produced, and as is well known there must follow a much less evolution of heat. In the more recent experiments the amount of carbonic oxide formed during the combustion of the carbon has been accurately determined, which has been done by passing the products of combustion first through a solution of potash, by which the carbonic acid is absorbed, and subsequently through a tube containing cupric oxide heated to redness. The carbonic oxide is thus converted into carbonic acid, which is passed through another potash solution and weighed. By these means the carbonic oxide, carbonic acid, and carbon are ascertained.

Calorific Power of Carbon.—Experiments have been made by Andrews and Favre and Silbermann on carbon, in the different states of diamond, graphite, and wood charcoal. The charcoal was freed from impurities by heating it to a dull red in chlorine, hydrogen, and nitrogen successively; and different specimens thus prepared gave the same calorific equivalent. The mean of a large number of experiments gives 8080, as may be seen in the above table, in referring to which the original results of the investigators will be stated instead of the equivalent in British units.

Favre and Silbermann discovered that, when carbon is burnt in protoxide of nitrogen, it produced a calorific equivalent 37·5 per cent. greater than when burnt in free oxygen.

Calorific Power of Carbonic Oxide.—Carbonic oxide has to be mixed with one-third of its volume of hydrogen in order to produce perfect combustion. The mean of two experiments gave 2403 units as the result of converting 1 gramme of CO into CO_2. Hence the amount of CO which contains 1 gramme of C will evolve 5607 units; since CO contains $\frac{3}{7}$ of its weight of carbon, $2\frac{1}{3}$ parts of CO contain 1 part of C and $2403 \times 2\frac{1}{3} = 5607$. Hence a gramme of C will evolve $(8080 - 5607) = 2473$ units by conversion into CO, or less than one-third of the heat due to perfect combustion, and this has been accounted for by the large amount of heat rendered latent on the passage of the carbon from the solid to the gaseous state in combination with the first atom of oxygen.

Calorific Power of Hydrogen.—Favre and Silbermann give as the mean of six determinations 34,462, the weight of hydrogen consumed being calculated from that of the water collected.

Calorific Power or Total Heat of Combustion of Compounds.—From the above table and an analysis of the fuel, the total heat of combustion of compound bodies can be easily calculated.

Supposing the elementary composition of the fuel examined to be as follows:—

	Per cent.
Carbon,	86·48
Hydrogen,	3·04
Oxygen,	7·10
Ashes,	3·38
	100·00

it would be necessary to deduct from these numbers the oxygen, and the equivalent of hydrogen which combines with it, and to account as available for raising the temperature only the remaining hydrogen and carbon. In the above analysis the equivalent of hydrogen which will unite with the oxygen of the substance will be $\frac{7{\cdot}10}{8} = 0{\cdot}8875$, which, when deducted from 3·04, leaves 2·1525 as the weight of hydrogen which goes to generate heat. According to Favre and Silbermann's numbers in the foregoing table, the units of heat which this would produce may be expressed thus: $\frac{2{\cdot}1525}{100} \times 34462 = 741{\cdot}8$, and in like manner the carbon may be valued, $\frac{86{\cdot}48}{100} \times 8080 = 6987{\cdot}6$; making together $741{\cdot}8 + 6987{\cdot}6 = 7729{\cdot}4$ as the heating power of the fuel. In the same way may the value of any other kind of fuel be found.

In addition to the remarks already made with reference to the calorific power of carbon completely burned, carbon imperfectly burned, and carbonic oxide, the following remarks taken from Rankine's "Steam Engine" may be usefully brought in:—

"The burning of carbon is always complete at first; that is to say, 1 lb. of carbon combines with $2\frac{2}{3}$ lbs. of oxygen, and makes $3\frac{2}{3}$ lbs. of carbonic acid; and although the carbon is solid immediately before the combustion, it passes during the combustion into the gaseous state, and the carbonic acid is gaseous. This terminates the process when the layer of carbon is not so thick, and the supply of air not so small, but that oxygen in sufficient quantity can get direct access to all the solid carbon. The quantity of heat produced is 14,500 thermal units per lb. of carbon, as already stated.

"But in other cases part of the solid carbon is not supplied directly with oxygen, but is first heated, and then dissolved into the gaseous state, by the hot carbonic acid gas from the other parts of the furnace. The $3\frac{2}{3}$ lbs. of carbonic acid gas from 1 lb. of carbon are capable of dissolving an additional pound of carbon, making $4\frac{2}{3}$ lbs. of *carbonic oxide* gas; and the volume of this gas is double of that of the carbonic acid gas which produces it. In this case the heat produced, instead of being that due to the complete combustion of 1 lb. of carbon, or 14,500
falls to the amount due to the imperfect combustion of 2 lbs. of carbon, or $2 \times 4{,}400 =$ 8,800

Showing a *loss* of heat to the amount of...... 5,700
which disappears in volatilizing the second pound of carbon. Should the process stop here, as it does in furnaces ill supplied with air, the waste of fuel is very great. But when the $4\frac{2}{3}$ lbs. of carbonic oxide

gas, containing 2 lbs. of carbon, is mixed with a sufficient supply of fresh air, it burns with a blue flame, combining with an additional $2\frac{2}{3}$ lbs. of oxygen, making $7\frac{1}{3}$ lbs. of carbonic acid gas, and giving additional heat of double the amount due to the combustion of $1\frac{1}{3}$ lb. of carbonic oxide; that is to say, ... $10{,}100 \times 2 = 20{,}200$
to which being added the heat produced by the imperfect combustion of 2 lbs. of carbon, or.. 8,800

there is obtained the heat due to the complete combustion of 2 lbs. of carbon, or
$2 \times 14{,}500 = 29{,}000$

"If the total heat of combustion of olefiant gas be compared with that of its constituents taken separately, the result is as follows:—

$\frac{6}{7}$ lb. carbon; $14{,}500 \times \frac{6}{7}$ .... = 12,430
$\frac{1}{7}$ lb. hydrogen; $62{,}032 \times \frac{1}{7}$ .... = 8,862
Total heat of combustion of 1 lb. of olefiant gas as computed by adding together the quantities of heat produced by the combustion of its constituents separately, ... 21,292
As found by direct experiment,......... 21,344

The difference,............... 52

is within the limits of errors of observation.

"Similar comparisons, for other hydrocarbons, give the same result. From these facts it is concluded, that *the total heat of combustion of any compound of hydrogen and carbon is the sum of the quantities of heat which the hydrogen and carbon contained in it would produce separately by their combustion.*

"In computing by this rule the total heat of combustion of a compound, it is convenient to substitute for the hydrogen a quantity of carbon which would give the same quantity of heat; and this is done by multiplying the weight of hydrogen by

$$\frac{62{,}032}{14{,}500} = 4\cdot28.$$

"It appears from experiments by Dulong, by M. Despretz, and others, that in computing the total heat of combustion of compounds containing *oxygen* as well as hydrogen and carbon, the following principle is to be observed:—*When hydrogen and oxygen exist in a compound in the proper proportion to form water* (that is, by weight, 1 part of hydrogen to 8 of oxygen), *these constituents have no effect on the total heat of combustion.*

"It follows, that if hydrogen exists in a greater proportion than is necessary in order to form water with the oxygen, only the *surplus* of hydrogen above that which is required by the oxygen is to be taken into account.

"From the preceding principles is deduced the following general formula for the total heat of combustion of any compound of which the principal constituents are carbon, hydrogen, and oxygen:—

"Let C, H, and O be the fractions of 1 lb. of the compound which consists respectively of carbon, hydrogen, and oxygen; the remainder being nitrogen, ash, and other impurities.

"Let h be the total heat of combustion of 1 lb. of the compound, in British thermal units. Then

$$h = 14{,}500 \left\{C + 4\cdot28\left(H - \frac{O}{8}\right)\right\}$$

Let E denote the theoretical evaporative power of 1 lb. of the compound, in pounds of water evaporated from and at 212°. Then

$$E = \frac{h}{966} = 15 \left\{C + 4\cdot28\left(H - \frac{O}{8}\right)\right\}."$$

Calorific Intensity, or Pyrometrical Heating Power of Fuel.—By the calorific intensity of a fuel is understood the degree of temperature which can be produced by complete combustion. This depends on the state of the atmosphere as to pressure, tension, humidity, and temperature, on the nature of the products, and the area of combustion. One of the data that is required for obtaining the calorific intensity from the calorific power of fuel is the specific heat. This element is known to vary and increase with the temperature, but no means are available for obtaining it experimentally at furnace temperatures, and it is therefore employed in this sort of calculation as a constant quantity. The calorific intensity is thus calculated to be much greater than it really is, and is in reality only hypothetical. Assuming, then, the specific heat to be constant, and having the expression of the units of heat generated, it is easy to find the thermometric temperature which it produces; to do this, however, involves the necessity of knowing the quantity of air required for consuming the matter, and likewise the specific heat of the products. It is well known that air is composed of 77 parts of nitrogen and 23 of oxygen, of which constituents only the latter is available in combustion. Having a knowledge of the proportionate quantity of oxygen required to burn the combustible elements, the volume of air containing this proportion may be readily found. Thus, every part of carbon combines with 2·6 of oxygen, which is yielded by 11·59 of atmospheric air; upon similar grounds the air required for the combustion of hydrogen is 34·78 parts. In both cases the products are carbonic acid, water, and nitrogen, the weight of which may be ascertained from the data given. Now the heat produced by the combinations of these distributes itself among the gases, so that they all indicate the same temperature, which can be estimated, assuming the specific heat of these bodies is known. The number thus obtained, and which represents the temperature of combustion, varies, however, with the nature of the fuel; and owing to our ignorance of the specific heat of the gases at a high temperature, the results should be viewed only as an approximation.

As an example of the calculation of the pyrometrical heating power of a fuel that already submitted may be again taken. It has been shown that the absolute heating effect of this specimen is 7729·4 units of heat, and that 0·8875 of the hydrogen contained in it is taken up by the oxygen, leaving 2·1525 of that element to undergo combustion with extraneous oxygen. It has been likewise stated that 11·59 parts of atmospheric air are required for the complete combustion of one of carbon, and, upon the same grounds, that hydrogen requires 34·78; hence the weight of air required to convert the carbon and hydrogen of the fuel into carbonic acid and water would be—

11·59 × 86·48 = 1002·3 parts for the carbon, and
34·78 × 2·1525 = 74·8 " hydrogen;

making a total of 1077·1

From these are produced } 326·5 parts of carbonic acid,
19·37 " water, and
819·88 " nitrogen, to which it
is necessary to add } 8·00 " water, formed by

the union of the oxygen of the fuel with part of its hydrogen; making a total of 27·37 = 19·37 + 8·0 parts of water. The specific heat of carbonic acid being 0·217, the amount of heat required to raise 326·5 parts 1° would be 326·5 × 0·217 = 70·85

The specific heat of aqueous vapour is 0·48; hence } 27·37 × 0·48 = 13·14
The co-efficient for nitrogen is 0·244; therefore, } 819·88 × 0·244 = 200·05

284·04

this number expresses the total amount of heat carried off by the products of the combustion of 100 parts of the fuel; hence

$$7729{\cdot}4 \div \frac{284{\cdot}04}{100} \text{ or } \frac{7729{\cdot}4 \times 100}{284{\cdot}04} = 2721{\cdot}2;$$

which number represents the thermometrical heating effect of one part. In this calculation the specific heat of the ash has not been taken into account; but the quantity of heat lost in this way is so insignificant that the results are but very slightly affected by it.

Pursuing the same course, the pyrometrical heating effect of any other kind of fuel or combustible, however numerous its ingredients, may be ascertained; that is, by finding the absolute heating power by the formula already given for the purpose, and dividing it by the sum of the specific heat of the products multiplied by their total weight, the quotient will be the available heat for any particular work when the fuel is burned.

It may here be remarked, that when a fuel is consumed in oxygen gas, the pyrometrical effect is much greater than when the combustion takes place in ordinary air, although the units of heat are the same in both cases. The difference of effect arises from the fact, that the nitrogen of the air passing through the fire in considerable quantities, renders latent a large amount of heat—the difference between the indication in oxygen and air.

The following table shows the heating effect of a few combustibles, as well when burned in oxygen gas as in air, calculated according to the above formula:—

Name.	Symbol.	Pyrometrical Heating Power.	
		In Oxygen.	In Atmospheric Air.
Carbon,	C	9753°	2450°
Carburetted hydrogen,	CH	4944	2286
Ether,	C_4H_5O	4035	2070
Light carburetted hydrogen,	CH_2	4703	2273
Alcohol,	C_4H_5O,HO	3407	1870
Hydrogen,	H	3491	2248

It may likewise be inferred from these results—calculated from the absolute heating power of carbon and hydrogen, and from the specific heats of the products, that hydrogen, which affords higher numerical results than any other combustible, as expressive of the absolute heating power, is among the worst kinds of fuel for producing a pyrometrical effect; and that carbon ranks far above it in this particular. The difference is slightly enhanced, however, in favour of carbon, by the circumstance that this element must attain a red heat before combustion occurs. The reason of this apparent anomaly with reference not only to hydrogen, but to all inflammable fuels, whether gaseous or fluid, may be traced to the circumstance, that the specific heat of carbonic acid is rather less than a half of that of the weight of water generated by an equivalent of hydrogen—being only 0·217—whilst that of aqueous vapour is 0·48. The same remark equally applies to solid fuels containing inflammable matters, such as oils or gases; and hence the advantage of the preliminary charring given to wood, peat, and coal, by which the relative amount of carbon is increased in the substance.

In these calculations reference is made only to the heating effect upon water; but in many applications of fuel, where a higher temperature is required than that of boiling water, as in metallurgical operations, &c., the pyrometrical effect of a combustible containing much hydrogen is considerably less than appears from the results stated, in consequence of the water which arises from the combustion of the hydrogen being in the one case dispersed in steam, whereas it is not so in the other. Now the quantity of heat necessary to evaporate 1 part of water at 212°, is calculated from the latent heat of steam to be such as would raise 5·367 parts of this liquid from 32° to 212°. All this is estimated in the calorimetrical experiments made for the determination of the absolute and thermometric heating power of the fuels mentioned in the preceding table, and consequently the results are much higher than would be indicated by the temperature in the furnace. It is quite certain that the capacity of other gases for heat increases with the temperature, and hence the discrepancy would be still greater. Assuming, however, that the specific heat of the other products of combustion remains the same at all temperatures, and that the water only removes the excess, the formula for correcting the results is simple and easy of application. Thus, all that is necessary is to multiply the entire amount of water resulting from the fuel, whether it be hygroscopic, or produced by the elements contained in it, or by the combustion of the hydrogen with atmospheric oxygen, by 536·7 = 100 × 5·367, for degrees Centigrade, and the product subtracted from the number found in the preceding will give the pyrometrical effect.

Having alluded to the process published by Berthier for the determination of the heating power of a fuel, the following tables are submitted as the results of his investigation; and though from what has been said in reference to Welter's theory, "that combustibles evolve the same amount of heat during their combustion with the same amount of oxygen," it follows that these results, from being founded upon it, are not quite correct, yet they give the approximate pyrometric values of the substances mentioned :—

I.—WOOD.

Species of Wood.	Dried in the ordinary manner. Berthier.		Containing nine per cent of water. Winkler.		Perfectly dried. Schodler and Peterson.			
	Pounds of lead reduced by one pound of wood.	Pounds of water which one pound can heat from 32° to 212°.	Pounds of lead reduced by one pound of wood.	Pounds of water heated from 32° to 212° by one pound of wood.	Pounds of oxygen required for the complete combustion of one pound of wood.	Pounds of water heated from 32° to 212° by one pound.	Air at 66° Fahr. required to consume one pound of wood.	
							in pounds.	in C. F, Hessian.
Oak,	12·5	28·3	14·05	31·82	1·358	39·82	5·83	154·4
Ash,	—	—	14·96	33·89	1·356	39·76	5·82	154·2
Sycamore,	13·1	29·7	14·16	32·07	1·394	40·85	5·98	148·4
Beech,	13·7	31·0	14·00	31·71	1·346	39·44	5·78	152·9
Birch,	14·0	31·7	14·08	31·90	1·376	39·73	5·82	153·0
Elm,	—	—	14·50	32·84	1·418	41·55	6·08	161·1
Poplar,	—	—	13·04	29·54	1·390	40·72	5·96	157·9
Lime-tree,	—	—	14·48	32·80	1·429	41·87	6·13	162·3
Willow,	—	—	13·10	29·67	1·352	39·61	5·80	153·6
Fir,	14·5	32·8	13·86	31·39	1·408	41·25	6·04	160·0
Pine,	13·7	31·0	13·88	31·44	1·392	40·82	5·98	158·2
Scotch fir,	—	—	13·27	30·06	1·393	40·85	5·98	158·3
Hornbeam,	12·5	28·3	—	—	—	—	—	—
Alder,	13·7	31·0	—	—	—	—	—	—
Larch,	—	—	—	—	1·408	41·25	6·04	160·0

II.—CHARCOAL.

Species of Charcoal.		Berthier.		Winkler.		
		Pounds of lead reduced by one pound of charcoal.	Pounds of water heated from 32° to 212° by one pound of charcoal.	Pounds of lead reduced by one pound of charcoal.	Pounds of water heated from 32° to 212° by one pound of charcoal	Air required for perfect combustion.
Commercial.	Poplar charcoal,	30·60	On an average 68	33·50	On an average of 75·7	On an average of 293·5 C. F. Air at 66° Fahr.
	Sycamore "	30·60		33·23		
	Ash,	29·60		33·23		
	Aspen,	29·50		—		
Enclosed in bottles immediately after being made.	Fir,	32·30	On an average 72	33·51		
	Alder,	32·40		—		
	Birch,	31·40		33·71		
	Oak,	31·30		33·74		
	Beech,	—		33·57		
	Elm,	—		33·26		
	Lime-tree,	—		32·79		
	Willow,	—		33·49		
	Pine,	—		33·53		
	Scotch fir,	—		33·62		

III.—PEAT.

Source of Peat.	Pounds of lead reduced by one pound of peat.	Pounds of water heated from 32° to 212° by one pound of peat.	
Peat from Troyes,	8·0	18·1	Berthier.
" Ham, dép. de la Somme,	12·3	27·9	
" Passy, dép. de la Marne,	13·0	29·2	
" Framont, dép. de la Vosges,	15·4	34·9	
" Ischoux, dép. Landes,	15·3	34·6	
" Konigsbrunn, Wirtemberg,	14·3	32·4	
Among twenty-four sorts from Hartz Mountain, the worst gave	11·9	26·9	Winkler.
The best gave	18·8	42·6	
From Allen in Ireland.			Griffiths.
Upper peat,	27·7	62·7	
Lower peat,	25·0	56·6	
Pressed peat,	13·7	28·0	

IV.—PEAT CHARCOAL.

Source.	Pounds of lead reduced by one pound of charcoal.	Pounds of water heated from 32° to 212° by one pound of charcoal.	
Crouy sur l'Ourcq, depart. Seine et Marne,	17·7	40·1	Berthier.
Seine et Marne,	18·4	41·7	
Essone, much used in Paris,	22·4	50·7	
Framont, and peat from Champ de Fue,	26·0	58·9	

V.—BROWN COAL.

Locality.	Pounds of lead reduced by one pound of coal.	Pounds of water heated from 32° to 212° by one pound of coal.	
Gemeinde Dauphin, Basses Alpes,	25·3	57·3	Berthier.
St. Martin de Vaud, Canton de Vaud,	22·6	51·2	
Minerme, department de l'Aude,	22·8	51·6	
Gardarme, Bouches du Rhône,	22·0	49·8	
Fuveau,	21·0	47·6	
Enfant Dort,	21·0	47·6	
Koep Fuarch, lake of Zurich,	20·7	46·9	
St. Lon, Basses Pyrenees,	20·3	46·0	

V.—BROWN COAL—(*Continued*).

Locality.	Pounds of lead reduced by one pound of coal.	Pounds of water heated from 32° to 212° by one pound of coal.	
Val Pineau, dép. Sarthe,	19·25	43·6	Berthier.
Common German,	18·40	41·7	
Edon, dép. de la Charente,	17·0	38·5	
Alpheus, Greece,	16·3	36·9	
Triphilis, “	16·3	36·9	
Kum, “	15·8	38·8	
Eibogen, Bohemia,	18·2	41·2	
Brown coal from Meissner,	20·1	58·9	Kuhnert.
Pitch coal “	15·9	46·6	
“ Ringkuhl,	16·9	49·5	
“ Habichtswald,	16·0	46·9	
Glance coal from Ringkuhl,	19·3	56·5	
Pitch coal from Habichtswald,	19·0	43·6	
Lowest stratum, Ringkuhl,	19·0	43·6	
Middle stratum,	10·0	43·9	
Stillberger coal,	14·1	41·3	
Lignite from Meissner,	14·7	43·1	
“ Laubauch,	17·5	51·3	
Earthy coal from Dax,	21·38	62·6	Regnault.
“ “ Bouches du Rhône,	18·89	55·3	
“ “ Lower Alps,	16·69	48·9	
“ “ Greece,	17·84	52·3	
“ “ Cologne,	18·24	53·4	
“ “ Usnach,	15·90	46·6	
Helmstadt, Prinz Wilhelm's mine,	20·17	59·1	Varrentrapp.
“ other mines,	21·83	63·9	
Schöningen, Gr. Irene,	18·76	54·9	
“ other mines,	18·60	54·5	

VI.—MINERAL COAL: CAKING COAL.

Locality.	Pounds of lead reduced by one pound of coal.	Pounds of water heated from 32° to 212° by one pound of coal.	
Coal from Dowlais, Wales,	31·8	72·0	Berthier.
Glamorgan,	31·2	70·7	
Eschwiller, near Aix-la-Chapelle,	31·0	70·2	
Lippe-Schaumburg,	30·9	70·0	
Newcastle,	30·9	70·0	
Carmeau, near Alby,	30·1	68·2	
Rive-de-Gier, Grand Croix,	29·6	67·0	
Mons, Bouleau-Fontaine-Madame,	29·0	65·7	
Canal coal, Wigan,	28·3	64·1	
Mons, Grand-Gaillet,	28·1	63·6	
Rochebelle, near Alais,	27·6	62·5	
Bouchamp, Haute Saône,	27·3	61·8	
Bessèges, Aveyron,	27·0	61·1	
St. Pierre la Cour, near Meyenne,	27·0	61·1	
Epinac, Saône-et-Loire,	26·8	60·7	
From Oviedo in Austria,	26·1	59·1	
Freuil mine, near St. Etienne,	25·4	57·5	
Bellestat, Aude—called jet,	24·4	55·2	
Jet—locality unknown,	23·3	52·8	

SINTER COAL.

Locality.	Pounds of lead reduced by one pound of coal.	Pounds of water heated from 32° to 212° by one pound of coal.	
Cherry coal, Derbyshire,	27·2	61·6	Berthier.
Soft coal,	26·3	59·5	

Locality and Species of Coal.	Pounds of lead reduced by one pound of coal.	Pounds of water heated from 32° to 212° by one pound of coal.	
Oviedo in Asturia,	26·1	59·1	Berthier.
Cannel coal from Glasgow,	24·9	56·4	
St. George's de Lavencas, Aveyron,	24·0	54·5	
Cannel coal from Lancashire,	23·5	53·2	
Ombrowa, Silesia,	21·2	48·0	
Salin, Jura,	21·0	47·5	
Vagas, Slavonia,	19·4	43·9	

SAND COAL.

Locality and Species of Coal.	Pounds of lead reduced by one pound of coal.	Pounds of water heated from 32° to 212° by one pound of coal.	
Durham,	31·6	71·6	Berthier.
Rolduck, near Aix-la-Chapelle,	31·0	70·2	
Zinsweyer, near Offenberg,	22·2	50·3	

VII.—COKE.

Species of Coke.	Pounds of lead reduced by one pound of coke.	Pounds of water heated from 32° to 212° by one pound of coke.	
A la Garre, from coal of St. Etienne,	28·5	65·6	Berthier.
From coal of Bessèges,	28·4	64·3	
“ Rive-de-Gier,	26·0	58·9	
Gas coke from Paris,	22·0	50·3	

VIII.—ANTHRACITE.

Locality.	Pounds of lead reduced by 1 lb. of anthracite.	Pounds of water heated from 32° to 212° by 1 lb. of anthracite.	
Anthracite, from Lamure, near Grenoble,	31·6	71·5	Berthier.
Anthracite from Pennsylvania,	30·5	69·1	
From Laval, la Chaumière,	33·0	74·7	
From Laval, la Baconière,	26·6	60·2	
“ Corbattiére in Savoy,	26·7	60·5	

The following is an abstracted table of the results of the experiments of M.M. Scheurer-Kestner and Meunier-Dollfus, between 1868 and 1874, in testing coals and lignites:—

They state that, since the commencement of their labours, Jamin & Amaury have demonstrated that the specific heat of water varies sensibly between the temperatures at which their trials were made; and that the employment of the formula of these gentlemen would augment by about 2 per cent. the tabulated quantities of the heat of combustion. The trials for the heat of combustion were conducted by means of the calorimeter of MM. Favre & Silberman.

All the numbers in the table have reference to the substance dry and pure; that is to say, to the combustible dried at 212° Fahr., and free from ash.

ANALYSIS OF FRENCH AND OTHER COALS AND LIGNITES, AND THE OBSERVED HEAT OF COMBUSTION.

Designation of Combustible.	Gaseous Elements.			Heat of Combustion of 1 lb. of pure Fuel.	Heat of Combustion of of 1 gramme of pure Fuel.
	Carbon.	Hydrogen.	Oxygen and Nitrogen.		
Coal—	Per Cent.	Per Cent.	Per Cent.	English Units.	French Units.
Ronchamp, 3 samples,	88·59	4·69	6·72	16,416	9,120
Saarbrücken, 7 “	81·10	4·75	14·15	15.320	8,511
Creusot, 4 “	90·60	4·10	5·30	16.994	9,441
Blanzy—Montceau,	78·58	5·23	16·19	14.985	8,325
“ anthracitic,	87·02	4·72	8·26	16.400	9.111
Anzin,	84·45	4·21	11·32	16,663	9.257
. evain,	83·94	4·43	11·63	16.290	9.050
English—Bwlf,	91·08	3·83	5·09	15.804	8,780
“ Powell-Duffryn,	92·49	4·04	3·47	16.108	8,949
Russian, Grouchefski, anthracitic,	96·66	1·35	1·99	14.866	8.259
“ Miouchi, bituminous,	91·45	4·50	4·05	15.651	8.695
“ Goloubofski, flaming,	82·67	5·07	12·26	14,438	8,021
Lignites—					
Rocher bleu,	72·98	4·04	22·98	11.670	6,483
Manosque, bituminous,	70·57	5·44	22·99	13.253	7,363
“ dry,	66·31	4·85	28·84	12,584	6,991
Bohemian, bituminous,	76·58	8·27	15·15	14.263	7,924
Russian, Toula,	73·72	6·09	20·19	13.837	7,687
Lignite passing to fossil wood,	66·51	4·72	28·77	11,444	6,358
Fossil wood passing to lignite,	67·60	4·55	27·85	11,360	6,311

The numbers cited in some of the preceding tables, as indicating the heating power of many kinds of fuel, appear at first sight contradictory to the known results obtained with such materials in the furnace. Thus considerably more heat is produced, judging from the work performed, when hard woods are burned than with the softer varieties; but numbers stated in the tables assign the greater heating power to the softer woods. Schödler and Petersen account for this apparent inconsistency by the difference in the amount of hydrogen producing unequal intensity of combustion in the two cases. They show that whilst woody fibre contains oxygen and hydrogen in the proportion in which they unite in water—that is, in the ratio of eight to one—all woods have the hydrogen in greater or less excess of the oxygen, and this excess acting at the temperature of combustion upon the carbon of the substance, produces a quantity of hydrocarbon gases, which are rapidly consumed. The residuary charcoal becomes in this case more porous, and therefore presents a larger surface to the oxygen of the air; the consequence of which is that it is much more speedily consumed than if it remained a dense compact body. Hard woods have less hydrogen than the soft ones, and this fact accounts for the difference in the amount of heat produced. The annexed table gives the excess in one thousand parts after the oxygen has been assimilated:—

	Excess of hydrogen.
Ash,	5·05
Oak wood,	5·08
Beech-wood,	6·50
Willow,	7·00
Birch,	7·50
Scotch fir,	7·70
Poplar-wood,	8·20
Maple,	8·30
Pine-wood,	8·80
Deal,	9·50
Elm,	10·00
Lime-wood,	13·90

In the other tables above given, it will be seen that the highest place is assigned to lime-wood in point of heating power; but in practical application the oak produces a better result. The difference of the time required for the combustion of the two accounts for the inequality. In the case of lime-wood, a considerable quantity of its carbon is taken up by the large excess of hydrogen, and is given off in the shape of inflammable gas, which presents an extended surface to the oxygen, and is consequently speedily consumed; the residuary charcoal burns rapidly on account of its porous nature, arising from the evolution of the particles of hydrogen and carbon. Now, oak-wood not having so large a percentage of hydrogen to react upon its carbon, of course a greater weight of the latter remains, and this being denser than in the case of lime-wood, a less surface is undergoing combustion in the fire, and a longer time will be occupied in its burning. It rarely happens that the arrangements for the application of heat in the arts are of such a nature as to allow of the entire economization of the heat produced, more especially when it is developed intensely and in a short space of time; hence, when soft woods are employed as fuel there is a considerable amount of heat lost, by which the working effect is lessened. On the contrary, with woods which burn slowly, the loss is not so great, since it is nearly wholly absorbed in proportion as it is developed by the combustion. The same remark applies to coals; and this is the reason why particular kinds are employed for steam-generating purposes, for glass and porcelain works; but although there appears a very great difference arising from this cause, yet it does not follow that the pyrometric effect of the one is less than that of the other. If, for instance, two equal weights of oak-wood be consumed, one in the form of chips or shavings, and the other in a compact mass, it will be seen that the former will burn in a much shorter period than the latter, and that the practical heating effect produced by the one will be much less than by the other. It is evident that the pyrometric heat is the same in both, only that the evolution of heat from the divided portion is so rapid as to cause the dissipation of a large part of it. Where a high temperature is necessary, it is evident that a fuel capable of giving off its heat in a comparatively short space of time is required; and hence the preference given to soft wood, or finely cleft hard wood, in the glass furnace and porcelain kiln. The facility which minute division affords for rapidity of combustion has, however, its limit, which, when exceeded, instead of expediting, retards, and when carried to extremes actually arrests combustion entirely, as may be observed with coal, coke, wood, and peat charcoal, when crushed to a powder. In this case the air has no access to the combustible except at the surface, so that the area of contact is very limited when compared to the bulk, and consequently ignition is arrested. When it happens that fuel in this minutely divided state is the only kind available, the combustion is assisted by piling blocks of limestone, sandstone, or other material upon the grate, and placing the fuel, such as sawdust, slack, brees, upon them, in which case the currents, ascending through the interstices, supply the requisite oxygen to the fuel. If the grate does not admit of this arrangement, the finely-divided combustible is converted into a valuable compact fuel by blending it with tar, pitch, or some such binding material, as described under Artificial Fuels.

In consequence of the defective furnace arrangements in most manufacturing establishments the quantity of heat absorbed and utilized bears, in general, no definite relation to the quantity produced, without taking into account the proportion of the fuel which is either not at all or only partially burned. The loss from these two causes alone has been estimated to be equivalent to the one-half of the coals consumed under the imperfect systems generally followed. Of late years considerable attention has been directed to discover some means whereby the cause of the first loss might be removed by an improved construction of the furnaces or fireplaces, with a view to their better retention of the heat, and marked benefits have arisen to many branches of trade, but more especially to those making extensive use of steam, from the various investigations instituted. Although the waste of heat from both the causes mentioned, namely, the non-retention of the heat and the imperfect combustion of the material, is very great; yet a considerable waste of fuel is occasioned by other circumstances which attend ordinary combustion, and which require investigation as much as the others. To enter into a minute discussion of all these would be tedious; but a short examination of the principal ones will be necessary, to point out the sources of the difference between the calculated value of fuel in heating power, estimated from experiments controlled in such a way as is not possible when the materials are burned in the ordinary furnace or grate, and that which results in practical operation.

In the first place, it will be evident that the mere maintaining of a fuel in a state of combustion, whether in a grate or furnace, involves and is dependent upon a certain loss of heat, as well latent as sensible, in the production and expansion of the gases resulting from the change, whereby they ascend from the substance and admit the fresh air to keep up the chemical action. It is well known that, under the provision made for burning fuel of any description, the air which is admitted must always be greater than the amount which theory assigns as sufficient, otherwise the combustion would be imperfect, and a heavy loss sustained. Admitting, however, that no more than is absolutely necessary passes through the fire, it will be seen, on reflection, that still a great amount of heat is rendered useless by the draught in the chimney, as already explained.

Another cause of the reduction of the heat, and the prevention of a due effect resulting from combustion in the furnace, is the water which is usually present in fuels in greater or less abundance. The loss suffered from this alone is twofold: firstly, inasmuch as the amount of real combustible is diminished by it, whether it be large or small; and, secondly, because by its conversion into steam, in which state it passes off with the products of combustion, it unites with a large amount of heat, which becomes latent.

When the proportion of water is appreciable, the quantity of heat which is wasted is very great. Wood, for instance, contains, after being dried in air, about one-fifth of its weight of moisture, so that when employed in this state as a fuel, only four-fifths of the weight taken is capable of generating heat. Supposing that 40·6 lbs. of water are heated from 32° to 212° by 1 lb. of wood perfectly free from moisture, it is evident that only 32·5 lbs. would be brought to the same degree by the available fuel in the pound of common air-dried wood. Further, the one-fifth of moisture is expelled in steam, and this takes up as much heat as would bring 5·5 lbs. of water from the freezing to the boiling point. Founding a calculation upon this fact, the one-fifth of a pound of water present would assimilate as much heat as would raise 1·1 lb. of water to the boiling point. By adding both, the total loss will be $9{\cdot}2 = 8{\cdot}1 + 1{\cdot}1$—or 22·5 per cent. less than if dry wood were employed. This example shows, in a striking manner, the great advantages which the employment of wood, peat, lignite, or such fuel as is liable to be more or less saturated with hygroscopic matter affords, when they are thoroughly exsiccated, over the same when containing 10, 15, or 20 per cent. of moisture. Where wood is much employed, care is taken to submit it to a preliminary drying operation, so that its combustion may be rapid, and that the loss described may be avoided.

It may be remarked, however, that water does not, under all circumstances, diminish the calorific effect of a fuel; but on the contrary, when judiciously managed, adds to it in a high degree. BUNSEN and FYFE have shown that aqueous vapour passed over incandescent fuel suffers decomposition; its oxygen is abstracted by the highly-heated carbon, and carbonic oxide results, while the hydrogen passes off partly uncombined and partly associated as carburetted hydrogen. These three products in the presence of sufficient oxygen, and the high temperature of the furnace, are capable of undergoing further combustion, and yield a large amount of heat by being converted into carbonic acid and water. In numerous experiments it was shown that the heat developed in this manner more than compensated for the fuel employed in producing the gases. The application of aqueous vapour, however, demands caution; for when used in too great an excess it reduces, rather than increases, the temperature of the fire. Its effect is to diminish the heat, unless used sparingly and with a free admission of air to promote the combustion of the inflammable gases.

The method in which water is utilized for raising the temperature is to place a vessel of this liquid beneath the bars, so that the heat radiated downwards may have the effect of producing the steam without further trouble; where steam-engines are employed, a jet of the waste vapour is allowed to issue under the furnace. A mistaken inference from this fact leads many to moisten the coals before throwing them on the fire, with a view to the increase of the heat; but that the contrary effect is produced is evident from what has been already detailed; the water in this case serves only to slacken the combustion, and render a considerable amount of heat latent. It is the practice especially to moisten small coals and slack when it is required to burn them on the furnace bars, and in this case the loss in heat from the presence of the water may to a certain extent be compensated by the advantage of the adhesion produced between the particles of the fuel, whereby it is prevented from falling into the ash or stoke-hole. Clay, plaster, or bituminous substances would serve better.

Besides the loss of heat which results from the gases or products of combustion passing in a superheated state into the chimney, as well as from the presence of an excess of moisture, there is another source of loss which is of far greater importance, and which is much more generally felt. It is necessary for keeping up the ignition that the column of air in the chimney be expanded by heat, and thus rendered specifically lighter than the surrounding atmosphere, and produce a constant current through the fire. The moisture in a fuel may be removed by a preliminary desiccation, the extent of the heat-absorbing surface may, under certain circumstances, be augmented, so as to arrest and economize a large amount of heat which might otherwise be lost; but to effect a complete combustion of the fuel, with the least possible volume of air, demands a thorough knowledge of the scientific principles involved in this change, as well as of the products resulting therefrom, together with the strictest attention on the part of the stoker. It is evident that a definite relation must exist between the weight of combustible elements in a fuel and the oxygen which is required to convert these into carbonic acid and water, and that to effect the latter change within the limits of this relation requires the most favourable circumstances, such as properly arranged furnaces, the adjustment of the fuel and draught of air passing through the fire, with skill and constant attention on the part of the fireman.

In a grate of any given dimensions, and burning a given weight of fuel in a determinate period, the quantity of air to be supplied can be easily deduced with the aid of known experimental results, as well as from theoretical calculations. Thus, it is known that 1 lb. of peat requires for complete combustion from 70 to 134 cubic feet of air at 66·2°; medium kinds of this fuel 149 cubic feet; 1 lb. of peat charcoal requires 155 to 228 cubic feet; 1 lb. of brown coal, according to the lead test, 139 to 222 cubic feet, and by analysis 160 to 248; 1 lb. of coal requires, by the lead test, 170 to 279, average qualities 228 cubic feet; according to Richardson's analysis from 248 to 303; by Regnault's, average qualities from the coal formation take 320 to 332, those from the secondary formation 293 to 326 cubic feet; 1 lb. of coke requires 194 to 250 cubic feet; 1 lb. of anthracite, according to the lead experiment, demands 233 to 277, according to Regnault's analysis, 312 cubic feet. A cubic foot of air weighs 0·07500 English at the above temperature.

Now, in these calculations it is presumed that the oxygen of the air is in contact with every particle of the fuel during ignition. Could the same condition be insured in the furnace it is evident that the great desideratum required in combustion would be attained; no escape of combustible gas could then ensue, nor of the carbonaceous particles which give to the gases passing up the chimney the character of smoke; and the greatest possible heat arising from the burning of the substance in air would be developed. Indeed, nothing would be wanting to extract from the fuel the benefit of its total theoretical heating power, but such an arrangement of the furnace as would perfectly utilize the heat so produced. No one, however, who has any experience as to the manner in which the fire is managed in the ordinary kinds of furnaces, will hesitate to assert that the above conditions are never supplied. The coals are thrown in thick layers upon the grate, by which the existing temperature for a time is greatly depressed, being absorbed in part by the cold fuel and by the dispersion of its hygroscopic matter. In addition to the reduction of the heat temporarily, the thick bed of fuel impedes the draught, and sufficient air cannot enter to effect a consumption of coals adequate to the generation of the amount of heat required. The portion of air which traverses the fire is deoxidized by the ignited fuel on the bars, and no oxygen for a considerable period can come into contact with the mass lying upon that which is burning; but although in this way it does not contribute to the pyrometrical effect, the temperature of the ignited mass, and the heated gases permeating it from below, cause a distillatory change by which the whole of the available hydrogen, together with a large percentage of the carbon, is expelled as hydrocarbon gases, which escape combustion. This decomposition, occasioned by the undue fuelling, does not only waste the combustible matter in the way alluded to, but it diminishes the heat which is produced by the portion that burns, since the gases in passing off carry with them a considerable portion of the heat as latent and sensible heat. Further, after the distillation of the gaseous matter is effected, and the residuary coke has acquired incandescence, an additional loss is sustained in consequence of the carbonic acid, in which the combustion of the carbon in the base of the fire terminates, being, by the deoxidizing power of the overlying glowing combustible, transformed into carbonic oxide, the abstracted oxygen taking as much again of the carbon as it would do if perfect combustion had occurred. The double volume of gas produced under these circumstances renders a large quantity of heat ineffectual for useful application.

It is thus that three radical and distinct sources of loss arise out of the profligate system of stoking usually practised, namely, waste of the volatile inflammable hydrocarbon gases of the substance, loss of the fixed carbon by the deoxidation of the carbonic acid, and lastly, loss of heat, as well in the state of latent as of sensible.

Independently of such gross waste in the application of fuel, another of no little moment exists, namely, the rapidity of the draught in the flues. Experiments have shown that in those cases where the flue has been lengthened with the view of affording a greater heating surface, the effect produced was materially affected by having the damper entirely withdrawn, or only partially so. Such a result is a natural one, considering the imperfect conducting power of air, and also of water, when it is on the point of passing into the state of elastic vapour; for the one does not transmit the heat to the fluid, nor does the latter combine with it so readily as to sufficiently abstract this principle from the gases when they rapidly circulate around the boiler and pass away. Ure illustrates this non-conducting quality of gases passing rapidly over a conducting surface by the slight elevation of temperature which is experienced in guns, cannon, &c., notwithstanding that the temperature produced by the combustion of the powder is very high. The reason is that the rapid evolution of the gases prevents the absorption of the heat by the metal. In the case of a furnace the barrel of the gun may be represented by the flue; the force of the explosion, and the products therefrom, by the draught and vapours produced in an ordinary furnace; and the effect of non-absorption in the latter instance will be as marked as in the former if the draught be too great. Hence it will be readily inferred that to utilize the whole or the greater part of heat, time must form an important consideration, to afford a more or less prolonged contact of the heated gases with the material of the boiler; consequently, where the draught is increased rather than checked within proper limits, the pyrometrical effect is to a considerable extent lost.

The causes of these losses in the production of heating effect, and consequently of mechanical power, have of late years engaged much attention, as well in America as in this country; and although the investigations, which have been conducted with a view to ascertain the conditions by which the largest amount of work might be performed by the fuel, have added materially to the knowledge of those circumstances that affect the heating power, they have scarcely touched upon those which relate to the economizing of fuel. Several modifications of furnaces have been patented of late years for the prevention of smoke, while at the same time it is alleged that the heat of the fire is increased; but it is to be feared that many of these arrangements, while ostensibly obviating one evil, produce others quite as injurious. This arises for the most part from the injudicious introduction of cold air at a part where the temperature is too low to cause combustion of the inflammable vapours and portions of carbon; or the quantity of air admitted is too great, and the heat rendered latent by it amounts to as much or perhaps more than in the ordinary fire. Much benefit will doubtless accrue from those improvements in the furnace by which the supply of fuel upon the grate is regulated, and rendered more or less independent of the stoker. By these the loss arising from imperfect combustion, as already explained, is to a great degree avoided. To enter into a discussion and notice of the several improvements would be, in some degree, foreign to the subject of this article.

Before proceeding to a particular description of the various kinds of fuel, their nature, and the processes by which various of them are prepared for particular uses, we will commence by describing briefly the methods of analysis which are usually employed in order to the determination of their constituents, from which, as already shown, their heating effect and their value for practical working in the furnace may be deduced.

Analysis of Fuels.—There are various processes whereby the composition of wood, charcoal, &c., may be found. Many of these are so simple, that any person having only a partial knowledge of chemical manipulation can conduct them with sufficient accuracy; several, on the contrary, require the experience of the advanced analyst to insure success. The examination, with reference to the quantities of carbonaceous and mineral matters, may be made by simply burning a weighed portion of the dried fuel in a tared crucible of platinum or porcelain till all blackness disappears, and only the white or brownish ash remains. The difference between the weight of the latter and that of the original substance will give the proportion of combustible ingredients. But before an estimate of the value of the fuel can be formed, something more than the preceding is necessary; and this will be evident from the consideration of its different applications in the arts and manufactures. For instance, the charcoal or coke manufacturer is chiefly interested in the quantity of solid products. The gas-maker, on the contrary, is mainly desirous to secure such materials as will yield the largest volume of gas, whereas the liquid products of the distillation, and the coke, engage only a secondary part of his attention.

To find in the simplest and readiest way whether a fuel, such as coal, is best adapted for one or other of these applications, it is necessary, in the first place, to weigh a sample, then to dry the weighed sample thoroughly, and to find, by again weighing it after desiccation, how much moisture it contained. The heat of a water-bath will serve for this purpose, but the following method is generally applied:—Sample (of coal) must be first pulverized. Then about 2 grms. are best dried between watch glasses at 105° to 110° C. for an hour, the loss being taken as moisture. Heating further would give a false increase in weight, due to oxidation of any finely divided pyrites there might be in the sample. Having determined the quantity of water, in order to determine the volatile matters, the largest gas works in the world heat about 2 grms. of the pulverized undried coal for four minutes over a Bunsen burner, and then without cooling for the same time over the gas blowpipe flame. The loss which appears on weighing will represent the liquid and gaseous matters present, and the residue, the coke or charcoal and mineral matters which the sample yields. If the percentage of mineral matters be already found, the quantity of carbon in the coke is estimated by deducting this percentage from that of the total amount of coke; but if the proportion of ash has not been ascertained, the crucible containing the coke is heated over a gas-lamp or in the muffle of a furnace, so arranged that a current of air shall circulate through it till all the charcoal is consumed.

In this way the quantity of moisture, of volatile matter—consisting of permanent gases and liquids—of coke, and of ash, which a fuel yields, is ascertained; and from them an average inference as to the value of the substance for the production of coke may be deduced, though not for gas-making, because it leaves doubtful how much of the volatile matter consists of inflammable gases, and how much of fluid products. When a very exact knowledge of a fuel is required, nothing short of an elementary analysis can be satisfactory; and this must be coupled with another, showing the quantities of the different products derived from the fuel, when acted upon by heat, out of contact with air. Even both these fail in some cases to give the information required in relation to many applications of the combustible.

By an elementary analysis, is understood the determination of the simple elements of matter entering into the composition of a substance. To enter fully into the particulars of such an analysis would rather confuse than enlighten the reader who may not be conversant with analytical chemistry, and those who are practised in organic analysis do not require a detailed description. A mere outline of the process will, therefore, be given. The first thing to be done is to rasp or abrade a portion of the substance into as fine a powder as possible. A certain weight of this powder is then to be desiccated either in the water-bath or over sulphuric acid in an exhausted receiver, or by passing over it dry air partially heated. The loss in either case will indicate the moisture it had contained. About ten grains of the dried matter are then taken, and intimately mixed with eight or ten times the quantity of chromate of lead or oxide of copper in a heated mortar, and immediately introduced into a dry combustion tube of hard German glass. Care must be taken that the oxidizing agent, whether it be chromate of lead or oxide of copper, be subjected to a red heat immediately before its admixture with the combustible, to insure the absence of water; also, that 20 or 30 grains of dry chlorate of potash are put into the inner part of the combustion tube, and an inch or two of the oxidizing agent, before the substance to be examined. Having rinsed the mortar with a fresh portion of the chromate or oxide, and added this to that in the tube, the latter is tapped in a horizontal position on the table, in order to form a channel in the upper part for the gases and vapours to flow over. A few fragments of copper turnings are placed in the front part of the tube, and then a little asbestos. Having introduced these, the mouth of the tube is secured by a cork fitted with a small piece of tubing for connecting it with a poised chloride of calcium tube, in which to intercept the water generated during the combustion. To the latter, another tube filled with a solution of caustic potash, specific gravity 1·26, and commonly known as a Liebig's apparatus, also previously balanced, is joined by means of a caoutchouc connector. The success of the experiment will very much depend on the connections of the various parts being quite secure. During the fitting of these parts, the tube may be placed in the combustion furnace. As soon as the several parts are carefully adjusted, a few fragments of ignited charcoal may be laid on the sealed end of the tube containing the chlorate of potash, and after the air of the apparatus is replaced by oxygen, the combustion is commenced by applying red-hot charcoal to the front of the tube. Care must be taken that the development of gas be not too rapid, as in this case portions may escape absorption; neither, on the other hand, must it be too slow, lest a vacuum be formed in the combustion tube, causing a reflux of the solution of potash, which would be fatal to the experiment. A steady even stream is kept up by extending the ignited charcoal to fresh parts of the tube as the evolution begins to slacken. After that part of it containing the combustible has been brought to a red heat, and no more gas is evolved, the fire is applied gently to the part containing the chlorate of potash, so as to produce a gradual stream of oxygen gas, the combustion tube being still kept at a red heat. This has the effect of forcing over into the absorbing apparatus any carbonic acid and aqueous vapour which may remain, and at the same time insures the entire combustion of any particles of charcoal that may not have been exposed to the full heat. Finally, the closed point of the tube is broken, and a U-shaped tube containing fragments of pumice-stone, saturated with sulphuric acid in one limb, and pieces of hydrate of potash in the other, is connected with it; suction is then applied at the open limb of the potash apparatus, to draw over all carbonic acid and moisture; after which the chloride of calcium tube and bulbs are detached and reweighed, and the increase in each case noted carefully, as from this the carbon and hydrogen of the substance is calculated.

The calculation is founded upon the data afforded by the composition of water and carbonic acid—namely, that 9 parts of the former contain exactly 1 of hydrogen, and 22 parts of the latter 6 parts of carbon. All the water resulting from the combustion of the hydrogen with the chromate of lead, &c., is retained in the chloride of calcium tube, and the whole of the carbonic acid, generated under similar circumstances, is absorbed in the bulbs; hence, when due care has been exercised, the results are very accurate. Sometimes a second chloride of calcium tube is attached to the apparatus for absorbing the carbonic acid, when the amount of nitrogen in the sample is appreciable, with the view of arresting the aqueous vapour which this non-condensable gas carries with it from the potash liquor. It will be evident, indeed, that in almost all cases this precaution ought to be adopted; for even when no nitrogen is contained in a substance submitted to organic analysis, the air drawn over at the termination of the combustion becomes loaded with moisture in passing through the bulbs, and so far the weight of the latter is reduced, on which account the amount of carbon found is less than the true quantity; but by attaching a second chloride of calcium tube, filled with fragments of this salt after being fused, and which should be weighed before and after the operation, and adding the gain to that of the bulbs, this error may be prevented.

Instead of compounding the substance with a solid oxidizing agent as in the manner described, it may be introduced at once, provided it has been previously dried, into the combustion tube in a tolerably coarse state, and a stream of pure dry oxygen gas passed over it. The tube should be open at both ends, one of which is to be put in connection with the reservoir of oxygen, and the other attached to the usual absorbing media. It is necessary that the oxygen be entirely free from carbonic acid and moisture, and for the greater safety it should be transmitted through a U-tube, holding in one limb fragments of fused chloride of calcium, and in the other pieces of solid potash, before entering the combustion tube. In this process it is absolutely essential that the potash apparatus should have a chloride of calcium tube connected with its escaping limb, otherwise the excess of oxygen would carry with it considerable quantities of aqueous vapour, and so reduce the indication from which the carbon is to be calculated. Connection of the several parts being made, a gentle stream from the reservoir is allowed to flow through till all the air is displaced. As soon as this happens, heat is applied to the tube by placing incandescent charcoal around it in the usual progressive way, the current of oxygen being still maintained, till it assumes a red heat, or nearly so, and it is kept in this state till all the carbonaceous matter of the substance operated upon is consumed. Gas may be very advantageously substituted for charcoal in conducting an operation of this kind. When all combustible matter is eradicated from the tube, the fire is slackened, and the current of oxygen maintained for a short time. The parts for absorbing the water and carbonic acid eliminated during the foregoing process are detached, wiped, and balanced, as already detailed, and the hydrogen and oxygen are calculated from their augmentation in weight.

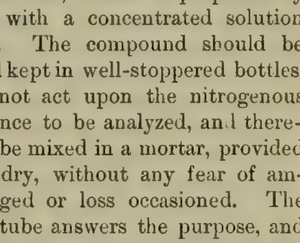
To estimate the nitrogen, a second combustion is in some cases requisite. When the quantity is ascertained volumetrically, the work may be accomplished at one combustion, by establishing a connection between those parts in which the hydrogen and carbon are retained as water and carbonic acid, and an apparatus for measuring the gas. A long combustion tube is required in this instance, so as to admit of a few inches of it being filled with copper turnings, to decompose any binoxide of nitrogen which may be produced during the action of the heat. The nitrogen traverses the chloride of calcium tubes as well as the potash bulbs, and finally enters the graduated tube, and displaces the mercury with which it is filled. When the operation is finished, some oxygen is generated from the chromate of potash, in order to force over all the nitrogen and other gases remaining in the apparatus. A portion of this oxygen enters the graduated jar or tube, and must be removed before reading off the volume of nitrogen. For this purpose, after reading off the volume of mixed gases, a quantity of hydrogen equal in bulk to this mixture should be added, and as soon as diffused a measured portion should be transferred into an eudiometer, and exploded by the electric spark. By noting the reduction in the portion taken, the quantity or volume of oxygen in the whole may be ascertained, from the knowledge that one-third of the decrease is oxygen. Deducting the volume of oxygen thus found from that of the mixed bulk of oxygen and nitrogen, the remainder will be the volume of the latter in the portion of the substance submitted to combustion, and from which the weight is deduced, since, at a barometric pressure of 30 inches and a temperature of 60°, the weight of 100 cubic inches of nitrogen is 29·2914 grains.

Will and Varrentrap's method is a considerable improvement upon the system of analysis pursued in the determination of nitrogen, inasmuch as it dispenses with the use of mercurial troughs, graduated measures, barometers, thermometers, &c.; it is besides much simpler and less laborious, for whilst numerous corrections have to be made for temperature, pressure, and the like in the old process, by this the work is most accurately performed by simply weighing. It is based upon the property which the fixed alkalies have of converting nitrogen, in whatever state it is contained in a substance, into ammonia, when aided by heat. The ammonia is fixed by an acid—generally hydrochloric—and subsequently in the form of ammonio-chloride of platinum, which is collected, dried, and weighed, and the nitrogen calculated therefrom; 222·5 parts of the salt representing 14 parts of the gas.

The agent used for the conversion of the nitrogen into ammonia is soda-lime, which is prepared by slaking caustic lime with a concentrated solution of hydrate of soda. The compound should be thoroughly dried, and kept in well-stoppered bottles. In the cold it does not act upon the nitrogenous element of the substance to be analyzed, and therefore both bodies may be mixed in a mortar, provided they are thoroughly dry, without any fear of ammonia being disengaged or loss occasioned. The ordinary combustion tube answers the purpose, and the course to be pursued is the same as that already mentioned for mixing the ingredients and heating, &c. The details of the estimation of the ammonia, quantitatively, have been already stated in the article Ammonia.

The modification of this process, introduced by Ullgren, may be advantageously noticed here. The combustion with the soda-lime is essentially the same in this as in the preceding operation; the only difference lies in the manner of condensing the ammonia. Fig. 12 represents the form of apparatus employed. In this cut, A and B are two U-shaped tubes, in the first of which the connector from the combustion tube opens; the upper portion of the first limb of the part A is charged with a plug of asbestos, *a*, and in the remainder, *b*, small pieces of hydrate of potash are placed; fragments of glass occupy the bend, *c*, and the second limb, *d*, is filled with little lumps of caoutchouc. A tube, *e*, bent at right angles, and passing

Fig. 12.



through perforated air-tight corks, connects A with B, which is filled with dry sulphate of zinc, and which should be accurately weighed before the experiment. The asbestos in the portion *a* prevents solid particles from passing by the force of the vapour upon the potash; the latter absorbs the carbonic acid and water, leaving the ammoniacal vapour and hydrocarbon gases to traverse further; the pieces of caoutchouc take up the combustible products, so that only the ammonia enters the tube, B, where it is completely absorbed by the zinc salt. To insure accuracy in this operation, it is directed that the part A be immersed in water marking 170° Fahr. before and after the experiment, so that any ammoniacal vapours contained in it may be driven over to B.

By weighing the tube B after the whole of the volatile alkali has been taken up, the increase of the weight will show the quantity of ammonia produced, and from this the nitrogen is found, for 17 parts by weight of the dry ammoniacal gas represent 14 of nitrogen.

Having, by one or other of these processes, arrived at the knowledge of the quantity of carbon, hydrogen, and nitrogen contained in the fuel, the oxygen, if any, will be the difference between the combined weight of the three and that of the entire organic or combustible matter. Sometimes, however, it is necessary to consider the sulphur in the analysis of coals, when this element is present in appreciable quantity; because, during the combustion of the substance in the air, it becomes oxidized, and passes off with the carbonic acid and water as sulphurous acid; and its quantity may be determined by deflagrating a known weight of the coal with about 2 parts of nitre and 8 or 10 of chloride of sodium, care being taken that both compounds be free from sulphuric acid; the sulphur is by this means oxidized into sulphuric acid, which becomes fixed by combining with the base of the nitre. By washing the mass with water, precipitating the acidified solution by chloride of barium, collecting sulphate of baryta, and drying, burning, and weighing the latter, the quantity of sulphur may be calculated. About five-eighths of the portion of sulphur should be deducted from the oxygen or loss expressed in the foregoing, and the difference taken as the true value of the oxygen contained in the compound.

Although the ultimate analysis gives a comprehensive insight into the nature of a fuel, and likewise a means of finding its heating power theoretically; still it leaves much to be desired in practice to enable one to form a correct estimate of its actual heating effect in manufacturing operations. Many circumstances concur to render the amount of work which a given quantity of fuel will perform less than theory indicates, the principal cause of the discrepancy being the want of such an arrangement of furnaces, as that the whole of the heat should be directed to, and actually enter into, the performance of the work to be done. This is a desideratum which can scarcely be expected to be attained in so complete a manner as to yield practical results, agreeing exactly with calculations founded on the nature of the fuel; the closer, however, that one can approach to this standard the greater will be the economy realized, and the nearer will the practical results coincide with the deductions of theory.

To arrive at an exact knowledge of the actual quantity of heat which a fuel ought to produce by combustion is impossible, no means being at hand for insuring definiteness to the result; but when, as in the determination of the atomic equivalent of a body, an arbitrary standard is taken, and the quantity of heat which other bodies produce is estimated with relation to such a standard, a comparative measurement is arrived at which, though not expressing the absolute amount of heat produced, serves all the requirements of the arts. The arbitrary standard assumed is the quantity of the fuel required to raise the temperature of a given weight of water a certain number of degrees, or the quantity of water which a given weight of the fuel or combustible will raise one degree. This amount, whatever it may be, is taken as the unit of heating power, and the number of such units, or the fractions thereof, which an equal weight of any particular fuel indicates by experiment, is taken as the heating or calorific power of that combustible.

The substances usually employed as fuel for manufacturing and domestic purposes are *wood*, *peat*, and *coal*, either in their natural state or modified by peculiar treatment. The abundance of these in a country must always constitute a principal source of its wealth, more especially now that steam has become the moving power of manufacturing industry, as well as the great agent in locomotion. It is evident, therefore, that none of the productions of nature should be more carefully husbanded than those which constitute fuel. Every attempt also to improve the quality of inferior materials, so as to increase their efficiency as heat-producers, ought to be liberally encouraged; and some efforts in this direction have lately been made with much success.

Wood, peat, and coal, though so different in physical appearance, are nevertheless very closely allied in composition, all the three being chiefly composed of ligneous fibre, a compound of three simple elements—carbon, hydrogen, and oxygen, with nitrogen and inorganic matter. Physical effects have induced certain changes in some kinds of peat and coal, which cause them to differ considerably in their properties from woody fibre; but by observing the action which analogous artificial agencies exert upon the latter, a remarkable coincidence is observed, and sufficient data are found for inferring that woody fibre is the basis of these substances, although they have passed in the course of time through various chemical transformations. The extent of the changes thus induced may be, to some degree, inferred from the phenomenon of combustion. Woody fibre, when deprived of extraneous moisture, readily bursts into a flame on being ignited, whilst many kinds of coal do not.

The difference is caused, firstly, by the states of density of these substances; and, secondly, by the absence of hydrogen and oxygen in the coal. Porosity and the presence of hydrogen in combustible bodies facilitates rapid combustion. When hydrogen is a constituent, it is liberated at a temperature below redness, in union with a portion of the carbon, from all the pores of the substance, and forms around the latter an inflammable atmosphere, which bursts into flame at slightly increased temperatures; the evolution of this matter leaves the remainder open to the passage of oxygen, which effects its rapid combustion.

The production of flame is always connected in a remarkable manner with the presence of hydrogen, but in some cases the phenomenon may be observed where this element is absent; thus, when pure charcoal or anthracite coal is burned in a limited supply of oxygen or air, instead of carbonic acid being generated, an inflammable gaseous body results, which re-ignites when a further quantity of air or oxygen is admitted, and produces flame. A characteristic difference is, however, observed between the sheet of light which is given out by a combustible containing hydrogen, and that from carbonic oxide; the former is luminously brilliant, as is seen in gas, whilst the latter is dull, bluish, and attenuated. The property of producing flame determines particular uses for many species of fuel, such, for instance, as choosing cannel for the manufacture of gas, and of inflammable varieties for the heating of reverberatory furnaces where the materials are at a distance from the fire. A selection of this class, for purposes where local heat is wanted, such as in the reduction of ores and in the manufacture of iron, would be injudicious, and consequently the less inflammable, or such as have been divested of hydrogen, are in these cases resorted to.

WOOD.—*Bois*, French; *Holz*, German.—This is the name given to the hard porous tissue of plants, through which sometimes the liquid sap is raised by capillary attraction, though more generally the latter traverses between the bark and these tissues. The wood of large trees is called timber, and is generally applied to architectural and domestic uses. It is only, however, in connection with its use as a combustible or source of heat that it will be discussed in the following pages.

Chemically considered, wood is composed of several substances, both of an organic and an inorganic nature, but of these the former alone are productive of heat. Woody fibre, or the tissue already noticed, constitutes the basis of the mass, whilst the sap, water, and other matters peculiar to the species of wood, make up the remainder. All kinds contain water and woody fibre, so that the sap and extractive matters are the substances which determine the particular species of this organic production. Thus many woods, especially the coniferous, are resinous; others, such as beech and birch, contain extractive matters; and many others, definite chemical compounds, such as tannin and the like. All these may be removed by the successive action of water, alkalies, and alcohol; and although the principles in the several varieties are different, yet they all afford a close approximation in the quantity of carbon, hydrogen, and oxygen which the wood contains.

Various concurring circumstances tend to enhance the value of wood as a fuel, such as freedom from water, and density, and it is upon these qualifications that its marketable value turns.

Amount of Moisture in Woods.—A remarkable variation is observed at stated seasons in the quantity of soluble matter (sap) which is present in all kinds of woods: thus, in spring, when the tree is in active growth, the amount of water is much greater than at the close of autumn or the middle of winter. The practical benefit of this knowledge is, that trees, whether intended for fuel or timber, are, or should be, felled in the latter seasons; although when they are cultivated for the principle of the sap, such as tannin and quinin, it is more advantageous to cut them when the flow is at its full.

Sap is unequally disseminated in various parts of trees: in the trunk it is accumulated more in the exterior than in the core, and still more in the branches than even in the outer portions of the trunk. Wood cut at the proper time retains from one-fifth to one-half its weight of moisture, part of which is lost by exposure to the air.

SCHUBLER and NEUFFER'S experiments give the following as the percentage of water in the several species enumerated:—

	Water Centesimally.
Hornbeam—*Carpinus betulus*,	18·6
Willow—*Salix caprea*,	26·0
Sycamore—*Acer pseudo-platanus*,	27·0
Mountain Ash—*Sorbus aucuparia*,	28·3
Ash—*Fraxinus excelsior*,	28·7
Birch—*Betula alba*,	30·8
Wild Service Tree—*Cratægus tormin*,	32·3
Oak—*Quercus robur*,	34·7
Pedicle Oak—*Quercus pedunculata*,	35·4
White Fir—*Pinus abies dur*,	37·1
Horse Chestnut—*Æsculus hippocast*,	38·2
Pine—*Pinus Sylvestris L.*,	39·7
Red Beech—*Fagus sylvatica*,	39·7
Alder—*Betula alnus*,	41·6
Aspen—*Populus tremula*,	43·7
Elm—*Ulmus campestris*,	44·5
Red Fir—*Pinus picea dur*,	45·2
Lime Tree—*Tilia europœa*,	47·1
Italian Poplar—*Populus italica*,	48·2
Larch—*Pinus larix*,	48·6
White Poplar—*Populus alba*,	50·6
Black Poplar—*Populus nigra*,	51·8

From the numerous experiments performed by CHEVANDIER, with the view of determining the loss sustained by woods of different ages, and by the several parts of the same tree when exposed to the air during stated periods, it may be inferred, that so far as the abandoning of moisture to air was observed, the soil and locality where the trees grew did not affect the results. The samples submitted to examination were exposed in a shed, which protected them from rain as well as from the sun's rays, and the moisture was determined at the several stages by drying a portion of the sample in the form of sawdust, at a temperature of

284° Fahr. *in vacuo*, till it ceased to lose weight. By this procedure it was found that the maximum loss by exposure was sustained, in the greater number of cases, after a period of a year and a half, although many specimens required two years to reduce their hygrometric contents in the same degree. It appeared, likewise, that the resinous varieties part with their water more freely than the non-resinous; they, on the other hand, absorb water with greater avidity when exposed to moist air than the latter. The softer non-resinous woods always contain more water when cut down than the harder kinds, but they part with it more freely, and can be desiccated to a greater extent than the latter.

The following is a synopsis of the results of researches on this subject:—

1. MEAN QUANTITY OF HYGROMETRIC WATER CONTAINED IN RESINOUS WOODS.

Parts of the Tree.	Percentage of Water.
Trunk-wood half a-year after felling,	29
Brush-wood "	32
Young Branch-wood "	38
Trunk-wood in the driest state,	15
Brush-wood "	15
Young Branch-wood "	15

2. MEAN QUANTITY OF HYGROMETRIC WATER CONTAINED IN THE NON-RESINOUS WOODS.

Parts of the Tree.	Percentage of Water.
Trunk-wood half a-year after felling,	26
Brush-wood "	34
Young Branch-wood "	36
Trunk-wood in the driest state,	17
Brush-wood "	20
Young Branch-wood "	19

These results may be viewed as the minima, because the single specimens would be more thoroughly exposed than if made up into stacks; and it may, therefore, be inferred, that after exposure under favourable circumstances during a year, the wood still retains about one-third of its weight of moisture, for the expulsion of which a prolonged heat is required. In ordinary air-dried firewood this amount of water, together with that which results from the oxygen and hydrogen contained in it, is vaporized at the expense of the carbon, and the consequence is that much of its value as fuel is lost when used in this state. In such applications where a brisk temperature is indispensable, the material is never used after merely air-drying, but is exposed to such a degree of heat as will drive off the moisture, so that, when ignited, the entire weight may be serviceable for the generation of heat. To do this thoroughly requires great care, because, unless the heat is sufficiently elevated, the moisture will not be removed, and when it is capable of exerting a thorough hydrotic effect, the constituents of the wood will be apt to arrange themselves so as to form gaseous matters, which are dispelled into the air, and thus a loss to some extent is sustained. Even when so treated that it does not retain any moisture, it becomes so hygrometric, that, upon exposure, it readily assimilates from 8 to 10 or more per cent. of water even in dry weather.

It has been found by J. R. NAPIER, as the result of experiment made on a large scale, that when wood is dried in an oven supplied with air at about 240° Fahr., 1 lb. of coal or coke suffices to expel 3 lbs. of moisture from the wood. If air dried wood were used to produce the same effect, from 2 to 2½ lbs. of wood would be required.

Density of different Woods.—When felled, nearly all kinds of wood are lighter than water, although the solid portions are possessed of a much higher density than this liquid; a few are, however, heavier than water, but these are the harder kinds, in which the cellulose is so closely packed together that very little room is left for the retention of air. In their ordinary state, water and air considerably vary in amount, and much difficulty is attendant upon the proper determination of the density. It will be understood, however, that so far as the moisture is concerned, it acts a neutral part, and the gravity of the solid portions is reduced by the volume of air in the pores. Again, as the hydrogen and oxygen of the woody fibre, as will be seen further on, are present in the ratio of their existence in water, or nearly so, and so solidified that they make up about the same volume as when actually combined in the form of water, it is evident that the greater weight of any specimen must be owing to the larger amount of carbon in the same bulk, excepting the slight difference which is due to the mineral constituents.

When common woods that are thoroughly dried and rasped so as to destroy their porosity are weighed with proper precautions, their density is found to be higher than that of water; and RUMFORD remarks that the solid portion of all the species of wood, wherever and under whatever circumstances grown, exhibits a remarkable identity in point of gravity, which he estimates at 1·46 to 1·53. Young woods are, however, specifically heavier than the older ones. The following table, based on different authorities, gives the density of several kinds of wood, water being taken at unity.

Variety of Wood.	Hartig.		Werneck.	Winkler.	Mushenbroek.
	I. Recently Felled.	II. Dried in Air.	III. Strongly Dried.	IV. Strongly Dried.	V.
Common Oak,	1·0754	0·7075	0·6141	0·663	0·929
Pedicle Oak,	1·0494	0·6777	..	0·663	..
White Willow	0·9859	0·4873	0·4464	0·457	0·585
Beech,	0·9822	0·5907	0·5422	0·560	0·852
Elm,	0·9476	0·5474	0·5788	0·518	0·600
Hornbeam,	0·9452	0·7695	..	0·691	..
Larch,	0·9205	0·4735	..	0·441	..
Scotch Fir,	0·9121	0·5502	0·4205	0·485	..
Sycamore,	0·9036	0·6592	0·5779	0·618	0·755
Ash,	0·9036	0·6440	0·6337	0·619	0·734
Birch,	0·9012	0·6274	0·5699	0·598	..
Mountain Ash,	0·8993	0·6440	..	0·552	..
Fir,	0·8941	0·5550	0·4303	0·493	0·550
Silver Fir,	0·8699	0·4716	0·3838	0·434	..
Wild Service,	0·8633	0·5910	..	0·549	0·874
Horse Chestnut,	0·8614	0·5749	..	..	..
Alder,	0·8571	0·5001	..	0·443	0·800
Lime,	0·8170	0·4390	0·3480	0·431	0·604
Black Poplar	0·7795	0·3656	..	0·346	0·383
Aspen,	0·7654	0·4302	..	0·418	..
Italian Poplar,	0·7634	0·3931	0·4402	..	..
Ground Willow,	0·7155	0·5289	..	0·501	..

At best, the density of wood leads but to a very vague and unsatisfactory conclusion regarding its heating power, although the fact of one sample being better than another in this respect may generally be inferred from its greater specific weight, which is a proof that it contains more carbonaceous matter in the same bulk. The condition of equal dryness, however, should not be overlooked, as without taking this into consideration the gravity deduced would be erroneous. From two-fifths to one-half the bulk of a stack of wood is interstitial space, even when the logs are of fair proportions; this is, however, much increased when small or crooked billets enter into its composition. It is only the quantity of woody matter that renders the material valuable as fuel; and a much nearer approximation to this can be arrived at when it is purchased by weight, than if the content is estimated by measurement. When, however, the purchaser is compelled to adopt the latter course, he should remember that the largest and straightest, as also the driest and densest varieties, are the surest to afford him an adequate value; the light, soft, and green woods not possessing sufficient matter to endue them with heating power in proportion to their bulk.

Value of different kinds of Wood as Fuel.—Very many considerations are to be taken into account in selecting wood as fuel, namely, the quantity of heat to be generated, the distance to which its effects are required to extend, and the length of time that the temperature must be sustained.

When soft light woods are burned, their action is brisk but transitory, their porosity favouring the rapid evolution of the volatile inflammable gases to which a part of their substance is converted by the heat; moreover, this looseness of texture allows the transmission of air freely through the mass of charcoal left, and consequently effects its rapid combustion. A remarkable exception indeed is cork-wood, which, although very light, affords more charcoal proportionally than any other species. When the wood is hard and compact, the heat cannot traverse it so freely; and the result is that the interior portions undergo a kind of consecutive distillation, the volatile matters being slowly disengaged from the surface. When these have produced their effect, a charcoal remains of a dense and close character, weighing fifteen or twenty times more than that which light wood produces. Submitted to combustion, the charcoal from dense wood burns much more slowly, owing to the smaller surface which it presents to the air, than that from the softer kinds. These facts lead to the conclusion, that the principal effect of soft light woods is produced by the flame, the charcoal they afford being comparatively of little value. The contrary is the case with heavy woods, the flame from which is feeble compared with the others; but their charcoal is far superior, and more than counterbalances the difference.

It has been shown, in a preceding part of this article, that incandescent charcoal is very much superior to flame in radiating power; or in other words, the quantity of heat given off from charcoal is considerably greater than that emitted from flame; and as the denser woods produce, for equal weights, a much larger amount of charcoal than the lighter kinds, it follows that much more heat will result from the former. Nevertheless, although light woods are less adapted for all heating operations in which radiation plays an important part, yet they may be employed with advantage where it is required to communicate an elevated temperature to objects distant from the fire-place, or a uniform temperature to solid bodies in large masses. Such are the reasons of their being preferred for glassworks, porcelain manufactories, &c., and even if a naturally dense material be employed for these purposes, it is brought to a suitable state by splitting it up into thin pieces, so as to render the combustion quicker, or to avoid the introduction of a useless mass of air into the furnace. On the contrary, blocks of dense wood are preferable for the heating of boilers and other similar purposes, because in this case the radiant matter is required to act directly on the surface to be heated, which communicates by contact the heat to the liquid in the interior, through which it is then diffused by convection. The superiority of the denser over the softer woods for consumption in ordinary household fires, where radiation performs the most important part, is a fact universally recognised in practice. For stoves, also, and for heating apparatus in general, the former are found to be more advantageous, because they afford a much more regular and prolonged heat than the lighter woods, without involving the necessity of constantly adding fresh material to maintain the fire.

In England, where wood is scarce and coal fields are numerous and extensive, the former is little employed as a fuel, except for some special purposes; but this is not the case in all other nations, and some European states in particular are almost entirely dependent upon wood for common consumption. On the Continent, fire-wood is divided into three kinds, namely, *new wood*, *float wood*, and *peeled wood*. The first is that which has been conveyed by boat or wagon from the forest to the place of its consumption; the second, that which has been floated upon the waters in the form of rafts, a mode of conveyance which causes a considerable quantity to be submerged during the passage; lastly, the peeled wood is limited to oak and certain other species, the barks of which have been removed for the sake of the principle they contain: it is generally composed of the smaller branches, and used in dwellings. Much of the value of the floated wood is lost by its submergence in the water, and this to a great extent counteracts the advantages of cheap transport. The loss arises from the solution of the principle of the sap in the water, and is visible in the density as well as in the volume, sometimes amounting to 1 lb. per cubic foot.

Solid Constituents of Wood.—Fibrous matter, water, sap, and mineral salts, are the proximate principles of wood of every description. The amount of water contained in different woods has already received a share of attention, and as the sap is of a different nature in every species, to enlarge upon it in all its varieties would unduly prolong this article. The further explanation of the proximate principles of wood will, therefore, be confined to the cellulose, lignin, or woody fibre, and the mineral constituents.

Lignin.—Woody Fibre or Lignin constitutes, as already stated, the main bulk of trees and mostly all plants, varying in texture from the delicate and friable pith to the hard shells of the seeds. Regarded in conjunction with the mineral matters, it may be termed the skeleton of their structure, wherein is contained the various secretions and other principles. When the fine raspings of wood are treated successively with boiling alcohol, water, weak solutions of potash, dilute hydrochloric acid, and ultimately boiled repeatedly with distilled water, there remains a white substance, which, when dried at 212° F., is this *cellulose* or *lignin.* Not only may it be procured from the hard wood, but the pith of trees and plants yields it even more freely. If this pith be reduced by rasping, and then washed successively with hot and cold water, digesting in a weak solution of potash, and afterwards subjecting it to the action of chlorine gas, the fibrin will be readily obtained. To complete the process, however, the digestion with the alkali is repeated, and this is succeeded by another with acetic acid, when, after affusing well with distilled water, and drying, a very pure lignin results. Many substances, such, for instance, as linen, cotton, paper, afford lignin in a much purer state than wood, owing to the treatment which the fibre of flax and cotton undergoes to prepare it for those manufactures.

Pure lignin is tasteless, colourless, and insoluble in water, alcohol, ether, and essential oils; it has a specific gravity of 1·5, and is resolvable into other compounds by acids, such as nitric and sulphuric.

From what has been said of the behaviour of lignin, it may be inferred that its composition is analogous to that of amylaceous compounds, or in other words, that it is made up of the elements, carbon, hydrogen, and oxygen; the latter two being in that proportion in which they form water. Gay-Lussac and Thénard were the first to arrive at the conclusion that this proportion existed between these two elements, and the analyses of Prout and others corroborated this view of the subject. To show the identity of lignin in the extensive circle of plants in which it is found, was a work undertaken and successfully accomplished by Prout; not, however, by having recourse to numerous analyses of the principle prepared from different plants, but by taking two products of very opposite physical characteristics, and submitting them to ultimate analysis. These were portions of lignin from the *box* and *willow;* the former being one of the densest, and the latter one of the lightest species of woods. After preparing the lignin by repeated treatments with boiling water and alcohol, it was submitted, after desiccation in air, to analysis, which gave the following numbers:—

	Centesimally.	
	Box.	Willow.
Carbon,	42·7	42·6
Water,	57·3	57·4
	100·0	100·0

By exposing the lignin thus analyzed to a temperature of 212°, as long as loss was sustained, it was found that 14·6 per cent. of the weight of the box and 14·4 per cent. of the willow disappeared. Upon examination, the dried substance showed the annexed proportions: —

	Centesimally.	
	Box.	Willow
Carbon,	50	49·8
Water,	50	50·2
	100	100·0

By comparing these numbers with the figures given by Gay-Lussac and Thénard, as representing the composition of the lignin of beech and oak, namely:—

	Oak.	Beech.
Carbon,	52·53	51·45
Water,	47·47	48·55

or specifying the quantity of the water-producing elements thus:—

Carbon,	52·53	51·45
Hydrogen,	5·27	5·41
Oxygen,	42·20	43·14

the coincidence of composition will become apparent.

By the action of heat the hydrogen and oxygen in this body are made to unite, and consequently, so far as the estimation of the value of lignin as a fuel is measured by the oxygen assimilated, they play no part, although it must be admitted that a certain quantity of heat is disengaged by the chemical action which is produced by their union, notwithstanding that this may be rendered latent by the dispersion of the water so generated in the form of steam. It is therefore the carbon which operates in developing heat by combining with oxygen, of which 138 parts are required to effect the conversion of 100 parts of wood, represented by 52 of carbon, into carbonic acid. The heat produced in this reaction is capable of melting 4888 parts of ice, or of raising 3666 parts of water from 32° to 212°. With these theoretical deductions the practical results of Rumford and Hassenfratz are in perfect accordance, giving 3600 to 3680 as the equivalent for dry woods. It must be observed, however, that all the heat is not produced by the carbon of lignin, as assumed in the above calculation; because the principle of the sap is retained. This, however, approaches so near in composition to woody fibre, and its quantity is so minute, that it does not cause any remarkable difference between the results of the ultimate analysis of dry wood and pure lignin, as the following table drawn up from the determinations of Schödler and Peterson shows:—

Species of Wood.	Carbon.	Hydrogen.	Oxygen.
Pure woody fibre,	52·65	5·25	42·10
Quercus robur,	49·43	6·07	44·50
Fraxinus excelsior,	49·36	6·075	44·57
Acer campestris,	49·80	6·31	43·89
Fagus sylvatica,	48·53	6·30	45·17
Betula alba,	48·60	6·375	45·02
Ulmus campestris,	50·19	6·425	43·39
Populus nigra,	49·70	6·31	43·99
Tilia europæa,	49·41	6·86	43·73
Salix fragilis,	48·44	6·36	44·80
Pinus abies,	49·95	6·41	43·65
Pinus picea,	49·59	6·38	44·02
Pinus sylvestris,	49·94	6·25	43·31
Pinus larix,	50·11	6·31	43·58

It should be remembered, however, that the ash, which, as will be presently seen, averages from 1 per cent. to a much higher proportion, has not here been taken into account, and consequently that the difference is greater than it would be if the mineral ingredients were left out. CHEVANDIER has investigated some woods, taking cognizance of this fact, and the several specimens being dried at 284° F., afforded the following results :—

ELEMENTARY COMPOSITION OF SOLID WOOD AFTER DEDUCTING THE ASH.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Mean of Analyses.
Beech,..........	49·89	6·07	43·11	0·93	7
Oak,............	50·64	6·03	42·05	1·28	5
Birch,..........	50·61	6·23	42·04	1·12	4
Aspen,.........	50·31	6·32	42·39	0 98	3
Willow,........	51·75	6·19	41·08	0·98	2

ELEMENTARY COMPOSITION OF BRUSHWOOD AND BRANCHES AFTER DEDUCTING THE ASH.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Mean of Analyses.
Beech,..........	50·08	6·23	41·61	1·08	8
Oak,............	50·89	6·16	41·94	1·01	4
Birch,..........	51·93	6·31	40·69	1·07	3
Aspen,.........	51·02	6·28	41·65	1·05	2
Willow,........	54·03	6·56	37·93	1·48	2

On the whole, it appears from what has been stated, that carbon, oxygen, hydrogen, and nitrogen, are the essential ultimate elements of vegetable products, and that the proportion in which they combine is very nearly the same in different plants. It is therefore not a little remarkable that the composition of even the same plants is found to vary slightly in different parts, as shown by the following table :—

COMPOSITION OF WOOD CUT FROM VARIOUS PARTS OF THE SAME TREE.

Nature of Wood.		Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.
		Elementary substances found in 100 parts of wood.			
Leaves,.................		45·015	6·971	40·910	7·118
Small branch,...	Bark, .	52·496	7·312	36 737	3·454
	Wood,	48·359	6·605	44 730	0·304
Middle-sized do.,	Bark, .	48·855	6·342	41·121	3·682
	Wood,	49·902	6·607	43·356	0·134
Large do.,......	Bark, .	46·871	5·570	44·656	2·903
	Wood,	48 003	6·472	45·170	0·354
Trunk,..........	Bark, .	46·267	5·930	44·755	2·657
	Wood,	48 925	6·460	44·319	0·296
Large root,.....	Bark. .	49·085	6·024	48·761	1·129
	Wood,	46·324	6·286	44·108	0·231
Middle-sized do.,	Bark, .	50·367	6·069	41 920	1·643
	Wood,	47·390	6·259	46·126	0·223
Rootlet, with branch,....		45·063	5·036	43·503	5·007

Mineral Constituents.—When wood is burned, it always leaves a certain amount of residue or ash, which consists of various alkaline and earthy salts that have been taken up from the soil with the sap. The bases or metallic oxides of this ash are potash, soda, lime, oxide of iron, and sometimes oxide of manganese; one or more of which are united with silicic, carbonic, sulphuric, and phosphoric acids, chlorine and sulphur. All woods have not the same percentage of inorganic matter contained in them, and as may be seen in the preceding table, it varies remarkably in different parts of the same tree, and also with its age.

According to SAUSSURE, the quantity of ash yielded by—

1000 parts of barked young oak branches was..	4 parts.
1000 parts of their bark,..................	60 "
1000 parts of an oak trunk 56 feet diameter,..	2 "
1000 parts of its bark,......................	60 "

BERTHIER, KARSTEN, CHEVANDIER, and others, have likewise directed their attention to this subject, employing air-dried wood as the subject of their experiments. The results are appended :—

ASH IN A HUNDRED PARTS.

	Berthier.	Karsten.		Chevandier.		
		In young wood.	In old wood.	Solid stem wood.	Wood of branches.	Brush-wood.
Silver fir—*Pinus picea*,..	0·83	0·15	0·15	—	—	—
Birch,.................	1·00	0 25	0·30	0·57	1·00	0·48
Scotch fir, *Pinus sylvestris*	1·24	0·12	0·15	—	—	—
Oak,...................	2 50	0·15	0·11	1·94	1·49	1·32
Lime,..................	5·00	0 40	—	—	—	—
Fir—*Pinus abies*,.......	—	0·23	0·25	—	—	—
White beech,..........	—	0·32	0·35	0·73	1·54	0·72
Alder,.................	—	0·35	0·40	—	—	—
Red beech,............	—	0·38	0·40	—	—	—
Aspen,................	—	—	—	1·49	[illegible]·38	—
Willow,...............	—	—	—	2·94	3·66	—

Action of Heat on Wood.—Having explained the constituents of wood, it remains now to examine the effects of heat upon it. As the tendency of heat is to subvert the power of the existing affinity between the elements of complex bodies, as well as to change their physical appearance, the simpler the substances submitted to its action—that is, the fewer elements composing them—the greater is the force with which they are held in combination, and the better do they resist the influence of heat. When several bodies enter into the composition of a substance, it readily yields to the decomposing effects of fire, especially if the constituents have an affinity for one another, whereby simpler combinations are produced. Products of organic growth are generally of this class, as they include several elementary matters which have a remarkable tendency to arrange themselves into simpler and more permanent compounds. Some of the ingredients of these bodies are of a volatile nature; hence. as soon as the force of the heat applied overbalances that of the affinity which binds them together in the peculiar state in which the vitality of the plant arranges them, they assimilate and disperse, whilst others are left in the solid state. When the matters submitted to the action of heat are out of contact with air or oxygen, the quantity and number of the compounds formed depend, for the most part, upon the intensity of the temperature applied; but when oxygen or air is admitted, and the action of the heat is still exerted, the bodies, already modified, will undergo another change, from which will result compounds of the simplest and most permanent character. The latter transformation is always accompanied by the phenomena of combustion, whilst the former is termed dry distillation.

The constituents of organic matters, acted upon by heat in the presence of air or oxygen, unite with the latter element, and form with it the simplest and most stable compounds which it is possible for them to enter into. This is shown in the conversion of the carbon, hydrogen, and oxygen of such bodies into carbonic acid, CO_2, and water, H_2O—two of the simplest and, at the same time, most permanent combinations. In the other method of acting with heat upon organic substances—that is to say, in close vessels or out of contact with air—the results are by no means so simple as those just described; because the conditions necessary for heat to exert its full effect upon them are not supplied; and hence, although the compounds formed are not so complex, and are more permanent than those from which they have been generated, yet they are far from being the simplest and the most permanent.

From the moment when the decomposing agency of heat begins to overcome the existing affinity of the elements in the organic body, three circumstances concur, either to multiply the formation of distinct but definite compounds, or to yield particular ones in larger quantities: these are, as already intimated, the temperature; the natural affinity of the existing elements, more especially at the moment of their liberation in the nascent state; and, lastly, their volatility. The effects of the temperature are first directed to the expulsion of oxygen and hydrogen, two elements which, from their permanently gaseous nature, are disengaged; they have, however, a very powerful affinity for one another, and consequently at the instant of their liberation this affinity is exerted, and they pass off, in conjunction, as water. When the two gases are present in that proportion in which they constitute water, a very low temperature, comparatively, will be sufficient to bring about their separation from the burning body in the manner indicated; but, on the other hand, if they be contained in a different proportion, then will the excess of the one or the other, at the instant of its liberation, attack the more fixed element—carbon—and give rise either to permanent gases, such as light carburetted hydrogen and olefiant gas, or to oily products of an analogous constitution.

Products of the Combustion of Ligneous Matter.—The number and nature of the bodies which, by a proper management of temperature, might thus be produced are still open to research. Those which have been identified are water, ammonia, acetic acid, pyroxylic spirit, or wood naphtha, and a mixture of resins and ethereal oils, denominated tar. In addition to these, a number of gaseous compounds is produced, such as carbonic acid, carbonic oxide, and light carburetted hydrogen. The nature of the products will vary according as oxygen or hydrogen preponderates in a fuel; thus, when it is rich in oxygen, the greater will be the production of carbonic oxide and carbonic acid, and the formation of hydrogen compounds will be limited, whereas if hydrogen be in excess, the latter will be most abundant. How large soever the proportion of both elements may be, it will be insufficient to eliminate the whole of the carbon in the substance; hence, when vegetable matters are subjected to destructive distillation in close vessels, a residuary charcoal is always left, which, if wood, compressed peat, and such like bodies be operated upon, possesses the same form as the original substance. The carbon from most kinds of the denser coals does not retain this form, owing to their partial fusion under the influence of the heat, which produces an amorphous mass. Different names have been given to these residues; thus, what is left after the distillation of wood or peat is called *charcoal*, whilst that manufactured from coal is termed *coke.*

Charcoal and Coke.—The preparation of both these substances has become an important manufacture, as well for the sake of the by-products which are obtained in the operation as for the carbonaceous matter itself. Carbon in some convenient form is of vast importance in the industrial arts, where great local heat is required. It has been already shown that this high temperature cannot be attained with the use of such substances as contain oxygen and hydrogen in definite proportions, since much of the heat which is produced by the ignition of such materials is necessary to disengage the volatile bodies to which they give rise, and when these are liberated the combustion is only partial; besides, the heat which results in this case cannot well be concentrated, and cannot be rendered very efficacious by radiation. It is only charcoal, and such bodies as will develop the greatest amount of heat from the smallest possible extent of surface, that can be employed with advantage in such operations as the smelting of metals, especially iron, and for the purposes of railway transport, &c.

Not only is carbon valuable as a fuel, it is likewise highly serviceable in many other respects; its uses as a disinfectant have been given under the heading DISINFECTANTS; it is likewise employed as an absorbent of many gaseous bodies, for depurating sirups and extracts, and as a manure. It is chiefly, however, in connection with its application as a fuel, and its superior heating effects, that the various methods of preparing it will be here detailed.

Carbon, of which charcoal and coke are modifications, is known in its native purity *in the diamond*, although, as may be supposed, the quantity of it found in this form is very small. The Ghauts in India, more especially Golconda, Borneo, and the Brazils, furnish this precious gem. In this state it possesses remarkable transparency, brilliancy, and hardness, to such a degree that in no one of these attributes has it a compeer. Its specific gravity is 3·336; it may be burned in an atmosphere of oxygen gas, or in the air, under the influence of a very high temperature, when it is converted into carbonic acid; and ROGERS, by acting upon it in a finely divided state with bichromate of potash and sulphuric acid, found that it is completely converted into this gas. With a BUNSEN's battery of one hundred plates, it may be fused into a mass resembling very compact coke.

A charcoal approaching the diamond in purity, though partaking of none of those qualities which render the latter so valuable, is prepared by heating non-nitrogenous matters, such as sugar, dextrin, and the like, to redness in close vessels; or by passing the vapour of alcohol, ether, or some carbonaceous oils, through tubes heated to whiteness. In either case a very pure form of carbon is left. As obtained by the latter process, charcoal is a brittle, black, insoluble, inodorous, and tasteless substance, capable of conducting electricity with freedom, but obstructing the passage of heat in a remarkable manner. It is unaffected by air or moisture, a quality taken advantage of in construction by charring piles, so that they may resist the bad effects of moisture; the interior surface of casks and barrels destined for holding water and such liquids are frequently scorched, both that the contents may be preserved wholesome and pure and that the soundness of the vessel may be secured. In a pure state carbon is infusible, or only fused in a slight degree by the greatest known temperatures.

Processes of Carbonization. — It is known from ancient records that the manufacture of charcoal from wood has been practised for more than two thousand years; and very little progress appears to have been made, till lately, in improving the process. Many obvious circumstances would concur to induce the carbonization of wood in early times, such as the trouble of carriage and the facility of charring it on the spot where it was felled. It has been shown that wood by drying loses sometimes as much as 40 to 50 per cent. of its weight; it also contracts in proportion, and if the heat be carried on to the point of charring, this contraction will reach to 20 or 25 per cent of the bulk: hence the advantage obtained by this process in point of carriage. The system followed was such as to require partly the intervention of the air, and involved the destruction of a portion of the woods, the loss being greater or less in amount according to the care bestowed and the precautions taken. The old course is still adhered to, with some slight modifications. Taken in connection with what has been already said as to the effect of heat upon wood and matters of an analogous composition, the following remarks may suffice to point out how far the admission of air and the application of an increased temperature affect the production of charcoal.

It is evident that when a piece of wood is ignited, the heat which destroys its elementary composition passes gradually inwards from the surface till the whole is permeated; and as each successive layer of fresh fibrous matter is attacked, the volatile compounds resulting from the oxygen and hydrogen of the substance will issue at every pore, thus producing a mixed atmosphere of aqueous and inflammable matters around the wood. The combustion of these without the surface of the solid matter prevents contact of the latter with the oxygen of the air; hence, as long as they are formed, the charcoal which is left after the decomposition of each successive layer of lignin remains intact. It is different when they cease to be developed, for then the oxygen of the air is admitted, and the temperature being sufficiently elevated to induce combination, the charcoal rapidly decreases, so that, if the oxygen continue to be supplied, nothing will be left but the small quantity of mineral matters contained in the wood.

So long as the action of the heat supplied is restricted to the first stage the results will be satisfactory; but when it enters upon the second inconvenience and loss are occasioned. In the common process it is impossible to exclude the air altogether, as the charring of the main bulk is effected through the agency of the complete combustion of a portion of the same material in the mass; nevertheless, by regulating the quantity and direction of the current, much of the loss incidental to this method would be avoided. For instance, in the carbonizing of two pieces of wood, of the same state of dryness and having equal dimensions, in a current of air to which the lighted extremity is presented to the current, while the ignited end of the other is averted from the blast, it will be found that the first of these will be speedily consumed, whereas the other, the charred portion of which is partly protected by the gases disengaged, disappears much more slowly, and sometimes leaves a residue of charcoal. Were it possible to introduce, as the distillation progressed, the parts of the second sample which was charred into a tube or vessel where it would be excluded from the air, a much larger amount of charcoal would result. Hence it may be inferred that, in charring heaps of wood with a movable coating of mould covering it from the air, the current should be led from the furthest and coldest extremities, that the gases, as they issue, may protect the matter already decomposed from destruction; and again, that the best course would be to effect what is termed the destructive distillation of the wood, keeping the matter subjected to this process entirely out of contact of air. Such a process of decomposition may be carried out in close vessels, and this is the one best calculated to afford the largest yield of charcoal; besides, by a little additional care and management, the various other constituents of the matter operated upon and modified, so as to exist in states which are more or less valuable in other applications, can be recovered and turned to profit.

Notwithstanding that by the process of destructive distillation in close vessels the greatest possible control is exercised over the operation, still, if the resulting charcoal be compared with the content of carbon in wood, it will be apparent that a considerable loss is sustained. According to the analysis of the samples of wood already laid before the reader, it would appear that the elements of oxygen and hydrogen, which exist in all of them in nearly the same proportion as in water, were removed, the charcoal remaining should constitute from 38 to 40, or even 45 per cent. of its weight, but in actual workings the yield is often so low as 15 to 20, and under the most favourable circumstances only 27 to 28 per cent. of the wood are obtained. The difference between the practical yield and that which theory would indicate is, in these cases, considerable, and is accounted for by the circumstance that the water, which is formed at a certain temperature, reacts upon the remaining charcoal, and, according to the degree of carbon which it possesses, occasions the formation of several other compounds, all of which are rich in carbon, deriving this from the charcoal, to the loss of the manufactured product. These different forms of combination proceed in the order of their oxidation, the richest in oxygen being given off first, and being succeeded by others containing less of this element, till, at the conclusion of the distillation, nothing is left, and the final products are composed of carbon and hydrogen. Thus, in exposing wood to heat in close vessels, the first bodies that are observed to pass off are water and carbonic acid, followed by acetic acid and carbonic oxide. These are succeeded by a highly carbonaceous oil of a deep brown colour and empyreumatic odour, which contains but little oxygen, and, lastly, carburetted hydrogen. As long as oxygen is in abundance the latter are not generated, and also they cease in part to exist when the temperature is very high, as the oil and acetic acid are incapable of resisting a high temperature without being mutually decomposed and resolved into water, carbonic acid, and carburetted hydrogen. The more oxygen and hydrogen that can be abstracted from the wood in the shape of water, the greater will be the bulk of the charcoal left; and to insure this the best course is to apply a heat which is only sufficient to cause the combination of those elements, although inadequate to produce the other products of a higher temperature.

The course sometimes adopted, of submitting wood which is much saturated with moisture to the action of heat, for the purpose of charring it, is disadvantageous, because the vapour of this body, passing over the portions already charred and partly incandescent, transforms them into hydrocarbons and carbonic oxide, and thus the yield of solid matter is diminished; indeed, if this decomposition were thoroughly effected, there would not be as much material as would supply carbon for this end. Woods, therefore, which are treated for the purpose of obtaining the largest amount of carbon or charcoal from them, ought to be well desiccated, so as to be divested of extraneous moisture, and then the temperature should be so controlled that the material will not attain a red heat, for, under the latter circumstances, the water produced from the elements of the wood would react in the manner above mentioned, to the detriment of the operation. M. KARSTEN made some experiments, with a view of ascertaining the relative effect of a low and high temperature, and found that if chips of wood were exposed for a long time to a heat of 300° F., they will ultimately cease to lose weight. The loss sustained when air-dried wood is so treated amounts to 65 or 70 per cent., but when the material is first desiccated at the temperature of the water-bath, the utmost limits are from 56 to 59 per cent. The residue in either case resembles charcoal in appearance, and was regarded as such by RUMFORD, who considered it as the skeleton of the plants; but KARSTEN has shown that it is but a modification of woody fibre, still holding matters which, when subjected to a high temperature, pass off as gases. However, the product from the application of a high heat is very different from that obtained when a low progressive one is applied, as shown by the results of KARSTEN's experiments in the subjoined table, to which are annexed the numbers given by STOLZE and WINKLER. The different varieties of wood taken as the subject of experiment by KARSTEN were dried in air, whilst those which WINKER operated upon were desiccated in a hot room, whilst STOLZE torrefied his at 212° Fahr.

TABLE SHOWING THE PRODUCE OF CHARCOAL AT HIGH AND LOW TEMPERATURES:—

Species of Wood.	By the quick process of charring	By the slow process of charring.		
	Karsten.		Stolze.	Winkler.
Young Oak,	16·54	25·60	26·1	22·8
Old do.,	15·91	25·71		
Young Red Beech,	14·87	25·87	24·6	17·8
Old do.,	14·15	26·15		
Young White Beech,	13·12	25·22	23·8	
Old do.,	13·65	26·45		
Young Alder,	14·45	25·65		
Old do.,	15·30	25·65		
Young Birch,	13·05	25·05	24·4	17·6
Poplar,	—	—	23·8	17·7
Old Birch,	12·20	24·70	24·4	17·6
Birch 100 years old, well preserved,	12·15	25·10		
Young Deal—Pinus Picea D.,	14·25	25·25	23·4	20·6
Old do..,	14·05	25·00		
Young Fir—Pinus Abies D.,	16·22	27·72	21·5	20·1
Old do.,	15·35	24·75		
Young Pine—Pinus Sylvestris,	15·52	26·07	23·7	
Old do.,	13·75	25·95		
Lime,	13·30	24·60	22·8	16·2
Ash,	—	—	22·1	19·4
Willow,	—	—	22·2	15·0
Rye Straw,	13·40	24·60		
Fern Straw,	17·00	27·95		
Cane Stems,	14·65	26·45		

It will be observed at a glance that the advantage of a slow process of carbonization in regard to the production of charcoal is in some cases double, and is, therefore, so profitable in this respect, as to warrant its being resorted to upon all occasions. A slight difference exists in the proportion of charcoal which many of the woods in the foregoing table afford, although the same course was followed in their carbonization. The probable causes of these variations are the changes of temperature which are liable to be experienced even within short periods in the course of manufacturing processes; and agreeably to this supposition, the widest range will be found between the results obtained at the high heat, where the variation was more likely to exist than in those samples charred at a low temperature. Taking the numbers in the second column of KARSTEN'S results as the maximum quantity which it is possible to obtain on the large scale, and comparing them with those which are arrived at by manufacturers who distil wood with the greatest precaution in close vessels, and who have in view the utilization of all the products resulting from the operation, this remarkable coincidence will be apparent. The general results obtained by these manufacturers may be expressed thus for 100 parts of wood:—

Charcoal,	28 to 30
Acid and water,	28 to 30
Tar,	7 to 10
Carbonic acid, carbonic oxide, carbide of hydrogen, and uncondensed water,	37 to 30

If to these numbers the weight of wood necessary to effect the distillation, and which is generally about 12½ parts, be added, the results will agree well with what is arrived at in practice in burning for charcoal. In air-dried wood containing about 45 per cent. of carbon, this element is distributed in the following manner:—

Charcoal left as residue,	30·00
" combined in the form of acetic acid,	0·50
" " in the state of tar,	6·00
" " as carbonaceous gases,	3·50
" required to effect the distillation,	5·00
	45·00

These results agree as closely as can be expected with the numbers given by theoretical calculation, assuming that there is no further disturbance of the elements beyond the union of the oxygen and hydrogen to form water, and the evaporation of this body together with the heating of the remaining charcoal to incipient incandescence, or to about 932° Fahr. Making these conditions the basis of the calculations it is found, theoretically, that to form the water from the elements in 112·5 parts of wood, and to dispel it together with the moisture in combination, which amounts to about 67½ parts, the heat developed by the combustion of 6 parts of charcoal is necessary. Proceeding in the same way, it is found that to bring the residuary charcoal to the above-mentioned temperature about 0·77 parts are required, making in all 6·77 parts. Practically, only 5 parts of charcoal are burned to perform this work; but, unfortunately, much of the carbon is carried away in the gases, so that the last number swells to 8½ or 9 parts of charcoal in the charring of the quantity already named. Even these figures are close enough to those deduced from theory to warrant the inference, that in the charring of wood no very considerable improvement towards producing a larger yield of carbon can be made upon the common method, by which from 25 to 27 per cent. of the weight of the original substance is obtained.

Having thus far enlarged upon the theory of the subject, the practical operations will now be considered. The distillation of wood has already been explained under ACETIC ACID, though chiefly with reference to the production of the latter body. It is now to be considered with special reference to the yield of charcoal; and with this object in view there are several methods of procedure, all differing, more or less, in their practical details, though they may all be classified under two methods, namely, such as require access of air, and those in which the air is excluded. The former includes all the different methods of charring in mounds, to which preference is generally given, to avoid the cost of transport.

The site of the mound, or *meiler* as it is termed on the Continent, is carefully chosen by the charcoal maker. Some spot is generally selected which is sheltered either by a declivity or a wood from currents of wind, and at no great distance from the felled timber. The soil must be neither too damp nor very dry; in the former case the moisture evaporated by the heat and passing over the charcoal, would at the high temperature convert much of the solid into gaseous bodies, and so occasion a loss; and in the latter, currents of air would enter through the interstitial channels, and prove as injurious as the humidity, or even more so. A spot which inclines to neither of these extremes is carefully cleared off in the summer time; and previous to erecting the meiler, if any misgiving is felt as to the fitness of the site, it is covered over with shingle or planks, and these are overlaid with charcoal powder to the depth of several inches. Having thus prepared the flooring, a stout stake is erected in the centre, having its upper end left crosswise at right angles; and into these incisions two logs are adjusted, forming right angles with one another in the same horizontal plane. Four logs are then inclined against the vertical post, the upper ends fitting into the angles produced by the intersection of the cross bars at the top. The floor or hearth of the meiler is then formed by placing billets of wood all round, radiating from the central post; the vacant spaces are filled with pieces of wood of smaller dimensions; and to secure the whole in the order in which they are laid, pins are fixed all round the periphery at about a foot distant from one another. Very dry wood, or such pieces as are easily ignited, are now arranged around the central post in a nearly vertical position, so as to form a truncated cone; these are inclosed by layers of billets of about equal length placed horizontally on the floor, and the vacancies filled up as before. Two or more such layers, forming concentric rings, are added, to increase the diameter of the mound, as shown in the sectional drawing, Fig. 13; and these, as they are successively raised, incline at the same angle as the nucleus around the central stake, owing to the logs being all cut of the same length, according to a regulation enforced by the forest laws. This is advantageous, inasmuch as it offers facilities for covering the whole more firmly with the soil or mould. When raised to the proper height the heap is rounded at the top by adjusting logs and brushwood together; and after this the whole is coated with a covering of soil from 4 to 6 inches, interposing grass, leaves, and such bodies between it and the wood. This coating does not extend to the bottom, but rests upon a layer of twigs and branches a few inches in thickness, held in their position by forked uprights, an arrangement adopted to allow of the escape of the aqueous vapours which are discharged by the first action of the heat upon the wood. Were the steam permitted to escape at the superior openings too much draught would be produced, and more air would thus be admitted than is advantageous to the working. The base of the meiler is protected from unfavourable draughts by an armour of wicker work, as seen in Fig. 14, representing the heap ready for ignition.

Fig. 13.

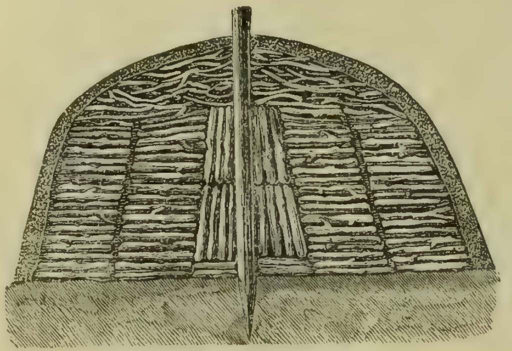
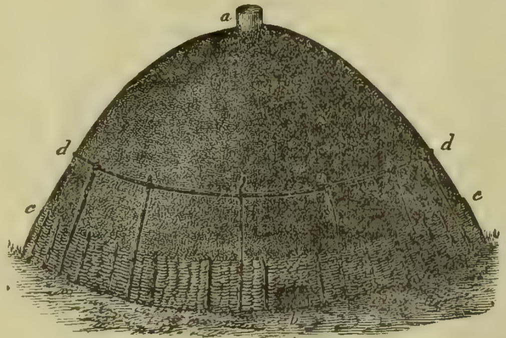


Fig. 14.



In this drawing *a* denotes the "quandel," *b* the aperture by which the mass is ignited, and *c* and *d* the armour surrounding the base. A few holes are left in the top and sides of the heap corresponding to the billets placed at the base. Care is taken to have the cover much more solid at the top, in proportion to the height to which the meiler is raised, so as to resist the draught which chiefly exerts its influence on this part of the heap. This mass is ignited by adding glowing charcoal to a quantity of brushwood which is placed in a channel at the foot of the meiler for the purpose; the fire rapidly traverses to the interior and attacks the logs which are arranged round the vertical stake; when these are red-hot the upper orifices are closed, and the first stage of the operation, namely, the "sweating," is then allowed to proceed. Much care is required to prevent a too copious disengagement of vapour at this period, which would destroy the heap; the process is going on well as long as the smoke presents the appearance of a yellowish-grey cloud. Much watery vapour is emitted at this stage, portions of which condense upon the covering of the heap, giving it the appearance of exudation. As the moisture is expelled the gaseous matter assumes a lighter grey appearance, which is the indication of the second stage of the process. The wood of the stake and portions of that surrounding it are now consumed, as well as the brushwood at the top; irregularities are, consequently, formed in the covering, owing to portions of its support yielding, and openings for the escape of the products of the combustion are produced. About this period the aperture which was caused by the annular support at the base, termed the "armor," is closed; after this, and on observing the above indications, the top part of the covering is removed as speedily as possible, the logs near the stake broken up and forced together with a long pole, and the empty space thus formed charged anew with more logs, the whole being secured under the mould as before. The entire combustion of the portion of wood in the centre, and of the smaller branches throughout the heap, now reacts upon the remainder of the logs, causing their destructive distillation.

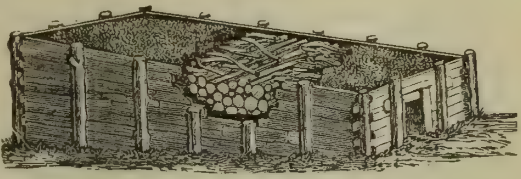
For several days the charring proceeds progressively towards the exterior of the meiler. During this time continual attention is necessary, as well in allowing the tarry vapours to issue at the base by making openings for that purpose, as in supplying air for maintaining the heat required for the charring, and checking the draught where the temperature and the combustion are too violent. As the work progresses and the wood becomes charred the heap contracts; but this is apt to be very partial unless the workman control the draught, by making outlets in the covering of that portion where the effect of the fire is slow, and drawing the heat to it, at the same time putting on a thicker coating where the action is likely to be too vigorous. Having done this in the upper part of the heap, it still remains to conduct the heat to the outer surface. The cooling tendency of the coating, and the condensation of water and empyreumatic matters upon it, render the ignition of the logs near the coating impossible under the circumstances hitherto stated; and if the operation were allowed to proceed the logs in the outer ring would be only half or three-quarters burned, even when the charcoal in the interior would be overdone. To guard against this a second series of holes must be made in the upper part of the breast of the meiler, in a line with those at the foot, but more distant; these openings need not, however, be made as high as there is wood uncharred, for the direction of the draught to this quarter will generate as much heat as will be sufficient to carbonize it, even above the temporary chimneys. From these orifices a thick black smoke is discharged, which after a time is succeeded by a thin blue cloud; as soon as this is observed the orifices made are closed, and others formed at a distance of two or more feet nearer the base, and the vapours allowed to issue by them till the same appearances are observed as before. According to the size of the heap, and the state of completion of the work in hand, a third and fourth series of such perforations are made in the covering, and the combustion of the matter in their vicinity is allowed to proceed till the heat is intense enough to decompose their elementary arrangement, after which they are closed. When the process is finished, flames issue simultaneously from the different apertures around the heap; and should this not be general, vents are opened in other parts in order to expedite the appearance of the flame all round. When this occurs the process is completed, and the duty of the attendant is now to extinguish the incandescent mass. Were this point overlooked, and the heap broken up before the charcoal was thoroughly cooled, no inconsiderable loss would be sustained; on the other hand, if it were left to cool spontaneously, too long a time would be required for this purpose, in consequence of carbon being a bad conductor of heat. The course adopted is to coat the whole heap with a thick layer of moist earth, and to leave it thus choked during a period which varies according to circumstances, generally twenty-four hours; if the temperature be not sufficiently reduced by this time, as much of the covering as is possible, without exposing the charcoal to air, is taken away, and replaced with another layer of the humid soil. If two coverings be given, the time allowed for its remaining on the heap is shortened.

When the whole is sufficiently cool for drawing the covering is stripped off, and the charcoal taken and spread upon the soil in a thin bed; should any sparks remain, it is necessary to exclude the air from these parts by throwing sand upon them. Another method is practised which, though more expeditious, is nevertheless more open to loss. It is to strip the meiler partly at the base, and by means of a hook to draw out the logs of charcoal separately and cover them instantly with sand, clay, or some such material as will readily extinguish them; water, when convenient, is employed for this purpose. When as many logs are abstracted from this opening as can be easily managed, it is quickly closed in order to prevent, as far as possible, the combustion of the incandescent charcoal; a fresh hole is then made at some distance, and the charcoal taken from it treated as before. This operation is repeated all round the base of the meiler till the whole is extinguished. Night is the best time for conducting this part of the work, as the darkness enables one to observe the smallest spark in the charcoal.

In the methods adopted in the New Forest, a different arrangement of the wood in the construction of the meiler is resorted to. The logs are placed perpendicular, or nearly so, around the central stake. In this case, instead of the central stake, three stakes are placed a foot apart, being retained at this distance with blocks of wood, and the empty space being filled with brushwood and half-burned charcoal. Red-hot coals are introduced at this portion, and in this case the horizontal passage is not required. The draught is so regulated that the heap may be carbonized from above, so as to form a cone with its apex downwards. This is arranged by drawing the volatile matter from the portion which is already carbonized. The effect of the fire is known by the depression of the carbonized mass, and the attendant, in watching the covering, knows where the openings for the draught should be made.

Another method of charring is in use, especially at Wienerwald, and also in mountainous districts where there is no great depth of soil, and where resinous wood is operated upon. The form of the heap or pile is shown in Fig. 15—a kind of structure termed *Haufenverkohlung*, and offering facilities of charring uncleft wood of every dimension. When this mode is adopted, it is customary to bark the wood, in order that the fire may attack it more readily than it would do if not so prepared. The best period for depriving charcoal wood of the bark is immediately after felling, for then the operation is easy, whereas if attempted when partly dried in the air, considerable difficulty would be experienced.

Fig. 15.

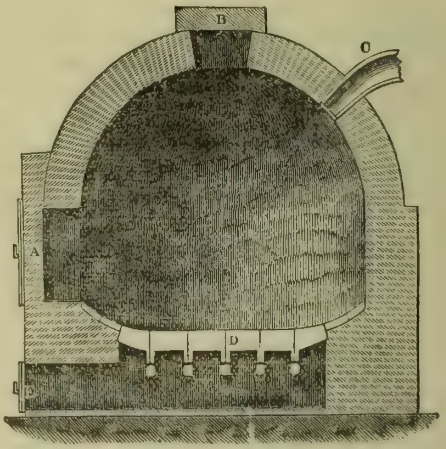


Heaps of a rectangular form always afford less charcoal than the meiler process, but the loss is in some measure redeemed by the circumstance, that the operation is more easily conducted in consequence of the vents and draught-holes being more under control in this than in the conical form. The site generally chosen for the heap is a gently inclined plane, about 7 to 10 feet in breadth, by 30 to 40 in length. Posts corresponding to the intended height of the heap are fixed vertically around this space and about 2 feet apart; to these boards are nailed, so as to retain in its place the covering of mould or powdered charcoal, as the case may be; sometimes wicker-work is substituted for boards. The logs of wood are now placed transversely to the length of the parallelograms, taking care to have the larger ones at the base, and to fill up with lesser wood all the intermediate spaces; sometimes, however, they are arranged lengthwise. As the heap increases, the upper surface is made to present a cuneated shape, by heightening the anterior part, and gradually tapering to an angle of 15° to 20° with the horizon. When finished, the heap is no more than 2 feet in height at the front, whilst it increases gradually to the opposite end, where it measures from 9 to 15 feet, according to its length. A small recess is allowed in the lower extremity, as seen in the figure, for the purpose of lighting. When the arrangements have been made for that purpose, and the heap is well covered with moistened charcoal or mould, and beaten as solid as possible, fire is placed in the chamber just mentioned, and the small wood contained in it quickly undergoes combustion; a draught is instituted by making several holes in the front of the heap, at a distance of about 15 inches from the level of the ground. As soon as the fire takes hold on the wood of the heap, the first opening is securely closed, and others opened along the front, so as to draw the heat along the base which is being charred, whilst the upper part is undergoing the sweating stage. When a light smoke of a bluish tinge issues through any of these openings, the attendant knows that the charring conditions are favourable in those parts, and that it is time to conduct the draught to other quarters, and for this purpose the openings already made are closed, whilst others are pierced in the covering at a proper distance. After the fire has traversed the entire breadth, the draught is still maintained by making perforations in the sides of the heap near the ground, and corresponding ones in the upper surface of the mound, taking care that the current thus instituted traverses only where the wood is undergoing distillation. The practice is to draw the charcoal from that part of the heap which has been charred as soon as the fire has extended as far forward as the heap is wide. This is continued partly throughout the operation, but so sparingly, that about half the heap will be left when the more bulky end comes to undergo active carbonization. The necessity of covering all the parts, and of sprinkling the surface of the heap with water to allay the heat in some degree, should not be overlooked. When this method is successfully conducted, the fire traverses about a foot and a half daily, causing the operation to last for a time proportionate to the length of the heap.

A method adopted in Sweden, which seems to be an improvement on the common plan, is to conduct the draught downwards instead of in the ordinary way; and if the pile were constructed upon a base sloped from the centre to the exterior, this would allow of the draining of the tar, acetic acid, water, &c., into a suitable vessel. Pipes might be disposed through it, so as to conduct the draught from the vertex to the base of the cone, and all converging into a tank, where the vapours would be condensed as far as possible, the remainder passing out through a flue into a chimney of sufficient height to generate a draught powerful enough to carry on the combustion. By this course all the heat would be utilized, and the moisture disengaged would be prevented from passing through the ignited wood—a circumstance which causes considerable reduction of the charcoal left.

If it is important to collect the products of distillation, the carbonization is generally performed in kilns. Of these there are two classes. In the first the charring is produced at the expense of a certain amount of the wood. In the second the fuel employed is quite distinct from that which is being carbonized. The following figure and description refers to the first of these classes of furnaces, which consists of a construction of brickwork, having apertures suited to the convenience of the workmen for charging and withdrawing the products. Of these, A shows the orifice through which the wood is introduced till it rises as high as this opening, after which it is closed, and the remainder of the interior charged through the superior aperture, B, and the orifice for the passage of the volatile products is through the pipe, C. These are more or less completely condensed by passing through tubes surrounded with water. The fire which serves to bring the contents to the point of decomposition is made on the grate, D, and the air which is to maintain its combustion enters by the ashpit, and is regulated by a door, E. When the kiln is charged, the apertures, A and B, are blocked up with bricks or closely fitting lids. As soon as the walls have acquired so much heat as will be necessary to complete the charring, the communication with the air is cut off by closing the door, E. In carbonizing in this manner, the charring is more regularly effected, although the supervision of the attendant cannot be so well exerted as when the ordinary meiler is resorted to; in the latter, however, the influence of the weather can scarcely be controlled, however watchful the workman may be—a condition effected by the walls of the kiln, and hence its superiority.

Fig. 16.



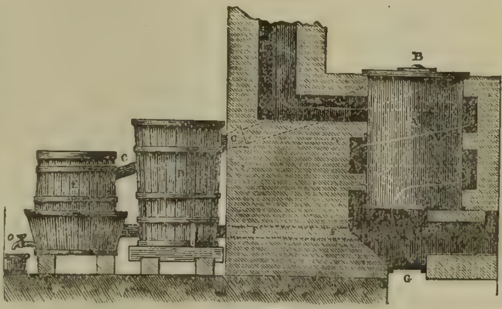
Differing from the kilns of this description, but still less advantageous in point of execution, are those kinds of carbonizers which char the wood without allowing the products of the combustion to come into contact with the materials to be decomposed. They possess an advantage over others, inasmuch as all the volatile products are recovered in the condenser, without anything being lost from combustion taking place in contact with them. This advantage is partly neutralized by the large amount of fuel which is required to bring their contents to the proper working temperature, and the necessarily small volume which must be operated upon, owing to the non-conducting qualities of wood and charcoal. No less than a quarter of the product in charcoal is consumed for this purpose, even when the combustible gases which pass through the condenser unarrested are economized in the grate.

The close distillatory apparatus or retorts are the most eligible for the decomposition of pine wood, and such as contain a large amount of resins; and though, at a distance from the site where the wood is felled, they are generally composed of iron, yet near the locality they are sometimes constructed of well-tempered clay. Those known as tar-retorts are composed of two hollow cylinders, one within the other, and differing 6 or 8 inches in diameter. The inner of these receives the wood, and is a little longer than the outer one. The space between them is appropriated to the fire, which is maintained by a current of air rushing in through apertures in the outer walls. A funnel shape is given to the base of the retort, and this is made to terminate in a pipe which traverses the outer cylinder, and abuts in a tar cistern where the products of distillation collect. By means of an aperture at the top of the inner cylinder the wood is introduced, and after the charging is performed, and all the outlets closed with the exception of those at the base, the fire is lighted in the intervening space between the outer cylinder and the retort, and the heat continued as long as volatile matters pass over to the receiver. When these cease, or sooner, provided the walls are sufficiently hot to finish the distillation, the fire is extinguished, and the apparatus allowed to cool.

A very good form of retort for the distillation of wood and the production of tar and charcoal is that shown in Fig. 17. annexed. The body, A, of the retort is of cast-iron, imbedded in masonry or brickwork, so that the flue from the grate courses spirally to the top, where it turns off to the chimney. In the upper part of this case is a movable cover, B, through which the wood is introduced, and by which the charcoal is removed when the charring is finished. An outlet is made at the top under the rim, to which a pipe, C, is fixed that communicates with a large condensing vessel, D, covered at the top; this is connected with another, E, wherein all the condensable matters which escape from the first are arrested and conducted to a recipient by the pipe and stopcock, *o*, whilst the non-condensable gases are reconducted by a pipe, F F, over the grate of the furnace, G, to be burned, and thus economize the fuel. The fire is made of faggots and brushwood, and is maintained till gases and vapours are abundantly evolved, at which stage a stopcock in the pipe, F F, is opened, and the inflammable products of the distillation are allowed to flow in over the fire, where, in burning, they produce as much heat, with a little addition of fuel, as will char the remainder of the contents. After the condensable matters cease to flow over this tap is shut, and the retort is left to cool for a period of sixteen or twenty hours.

Such are the principal methods resorted to for the manufacture of charcoal from wood for the requirements of the smelter, the powder-maker, and others. It is evident, from the nature of the several processes, that considerable difference must necessarily exist between the charcoals produced, as well in their intrinsic value as in their physical appearance. This partly depends on the species of wood employed; but all the difference is not to be attributed to this circumstance. The study of charcoal, with a view to its application in the works where it is chiefly consumed on the Continent, has led to a modification of the usual mode of charring, by which a larger volumetric yield has been insured, answering all the purposes required. This product is designated *torrefied wood* or *red charcoal*, from its reddish-brown appearance. BERTHIER was the first to call attention to this variety; whilst SAUVAGE conducted some experiments, from which he deduces that the amount of combustible matter obtained by the charring of wood does not increase after exposing the material to a suitable heat during a stated period, but that, on the contrary, a loss is sustained in the quantity. He limits the proper period to five hours and a half. The results of his experiments are transcribed in the annexed table, which shows the loss sustained in weight, and the volume at the intervals mentioned:—

Fig. 17.



100 lbs. Wood charred for	3 Hours.	4 Hours.	5 Hours.	5·5 Hours.	6·5 Hours.	Mound Charcoal.
Weighed	65·4 pounds.	53 pounds.	47 pounds.	41·5 pounds.	39·1 pounds.	17·2 pounds.
100 Cubic Feet by a similar treatment measured	86 C.F.	76 C.F.	58 C.F.	55 C.F.	52 C.F.	33 C.F.

When the following numbers are considered in connection with the preceding table, the loss sustained in combustible matter will become apparent:—

AMOUNT OF COMBUSTIBLE MATTER CONTAINED IN

1 cubic foot of wood,	908	parts by weight.
1 “ “ charred during 3 hours,	883	“ “
1 “ “ “ 4 “	904	“ “
1 “ “ “ 5 “	1133	“ “
1 “ “ “ 5·5 “	1091	“ “
1 “ “ “ 6·5 “	1136	“ “
1 “ meiler charcoal,	1096	“ “

Charcoal, in whatever way it is prepared, is dependent for its quality, as well as for the quantity, first upon the wood, and secondly upon the course of operations to which the latter is subjected. As to the former, the details already given of the composition of the different kinds will be sufficient to show that the amount of carbon in a given weight or volume is greater in some species than in others, and consequently these will yield a product containing more combustible matter for the same bulk than lighter woods. It is difficult, however, to make experiments decisive of the relative value of the various systems of charring in relation to the yield in carbon, or the relative loss of carbonaceous matter which woods sustain while undergoing decomposition by heat. Indeed, it may be said that most of the results of the investigations hitherto undertaken afford only approximations of the truth. The most accurate, perhaps, are those obtained by JUNCKER, who endeavoured to determine the yield of charcoal from samples of different kinds of wood, all about thirty-two years old. The woods were weighed and charred in heaps of equal size, using all possible diligence in the operation; and as soon as the charring was finished, and the product cooled, it was weighed immediately, and before moisture could be absorbed. The weights taken afforded the annexed results:—

	Centesimally.	
	Charcoal.	Half-charred wood.
Green red beech, cut in May, 1832,	19·7	0·6
“ “ without bark,	23·0	0·3
Dry red beech and oak, two years old,	24·0	0·3
Dry oak, two years old, and without bark,	25·7	0·34
Green oak, cut in May, 1832,	22·4	0·3
“ “ without bark,	21·2	—
“ “ with bark,	18·8	1·0
Equal parts of barkless red beech and oak, cut in Jan., 1831, and carbonized in Aug., 1831,	23·4	0·5
Green red beech with bark, charred immediately,	12·9	0·3
Green oak immediately charred,	13·5	0·4

The first five experiments were made in August, a season most favourable to the charring, and the others in January, a time less propitious; but when it is considered that the amount of water in the woods at the period of carbonization was left undetermined, and that this exercises a powerful action upon the charred substance, diminishing considerably the product, it is evident, from what has been previously said, that something is wanting to render the results conclusive.

Researches of a similar nature undertaken at Eisleben, where the operation of charring was effected in piles 30 feet in diameter, afforded the subjoined numbers:—

	Centesimally.	
	I.	II.
From Oak-wood in split logs,	21·3	23·4
“ Red beech,	22·7	
“ Birch,	20·9	
“ Beech,	20·6	
“ Pine,	25·0	

Other experiments with the same object have given, by the meiler process, results varying from 20 to 28 per cent., and averaging 23 per cent. of the wood taken, whilst the produce of the kilns in the same quarters has been shown to be only a mean of about 26 per cent.; and this, when the quantity consumed in the operation is deducted, leaves only about 22 per cent., or rather less than that afforded by the ordinary process. It must be remarked, however, that the meiler yield was in these cases an exception to their general produce, which is found much lower than the numbers so given, even when thick wood is operated upon; and the proportion is much further decreased when small wood is charred in them. It is a well-known fact, however, that none of the methods give, in the form of charcoal, more than two-fifths of the real amount of carbon in the dry wood. According to EBELMEN, this loss is occasioned not entirely by the products of the distillation carrying off portions of it in combination, but by the direct combustion of the charcoal in an incandescent state, caused incidentally by the oxygen of the air passing through it, and converting it into carbonic acid and carbonic oxide. This he proved by the comparative analysis of the vapours from the temporary chimneys in the meiler, and of those developed in close vessels, where contact of the fire was entirely excluded. Of course, if the portion of carbonic acid which must necessarily be generated is permitted to traverse the incandescent charcoal, it will suffer decomposition at that temperature, and as much more carbon as it contained will be assimilated and lost to the charcoal-maker, the whole passing off in the form of carbonic oxide. The charcoal-burner's efforts should be directed to prevent this, by conducting the air which enters the meiler over the uncarbonized wood; and after it passes that part of the heap where combustion is active, withdrawing it by means of the temporary openings in the cover, over the portion yet undecomposed, so as to be out of the reach of the made charcoal. It is almost impossible to effect this thoroughly, but the efforts made with that view by those engaged in the business show that its importance is appreciated, and doubtless a remedy will soon be found which will render the process more effectual than it is at present.

Quality of the Charcoal.—A few considerations may now be submitted with reference to the quality of the charcoal. Independently of the fact of the densest being the best, it happens that during the making it may be deteriorated, either by imperfect charring, or by pushing the process beyond the proper limits. In the former case the product is not good, on account of the gaseous elements which it retains, and which being disengaged in its subsequent application as fuel, render it less efficient for producing a high temperature; in the latter case it becomes so brittle as to be incapable of being handled without falling to powder: and the same crumbling occurs in the smelting furnace, where it is more injurious.

Good charcoal is very dark, possesses a bright lustre and somewhat conchoidal fracture; it resists gradual pressure to a considerable extent, and produces a sharp sonorous sound when allowed to fall upon a hard body. It should burn when ignited without either flame or smoke, and when handled no stain ought to remain. Although in bulk it floats in water, owing to the arrangement of the particles, its specific gravity, when ground so as to destroy its porosity, is much higher than that of water. In addition to the carbon of which it chiefly consists, a certain amount of oxygen, hydrogen, and other gases is found in it, together with the mineral matter of the wood. The greater or less proportion of the former affects its calorific power, and renders it more or less eligible for certain uses in the arts.

Red charcoal retains a somewhat larger quantity of the above gases than the product of the meiler or the close retort. The following table embodies the results of M. VIOLETTE's analyses of the charcoal prepared by the action of superheated steam, according to his process:

Species of Charcoal.	Elementary Constitution Centesimally Represented.			
	Carbon.	Hydrogen.	Oxygen, Nitrogen, and Loss	Ash.
Furze,	76·629	4·108	17·975	1·288
Iron wood,	72·564	4·527	12·510	0·399
Cork,	72·362	8·528	19·110	..
Juniper,	71·433	5·073	23·324	0·170
Wild pine-tree,	71·358	5·948	22·194	0·500
Hawthorn,	70·793	4·443	23·419	1·345
Palm-tree,	70·724	4·552	23·494	1·230
Ash,	70·395	4·539	24·374	0·692
Maple,	70·069	4·613	24·892	0·425
Cherry-tree,	70·028	3·928	25·289	0·755
Lime-tree,	69·829	5·452	23·024	1·695
Yew,	69·620	5·864	24·212	0·304
Sycamore—maple,	69·229	4·402	25·133	1·236
Medlar,	69·209	4·613	25·261	0·887
Chestnut-tree,	69·127	4·326	27·126	0·421
Willow,	68·900	5·133	24·634	1·333
Yoke-elm,	68·835	4·142	26·382	0·641
Poplar—trunk,	68·741	4·866	25·540	0·853
Coco-tree,	68·268	4·053	23·984	3·695
Hollyoak,	68·521	4·741	25·891	0·847
Aspen,	68·169	5·512	25·730	0·589
Ebony,	68·017	3·863	28·380	0·205
Oak,	67·421	4·099	28·480	0·200
Poplar—root,	67·020	5·217	26·675	1·088
Elm,	66·862	4 669	28·181	0 288
Plum-tree,	66·118	5·756	27·530	0·596
Pear-tree,	65·924	5·310	28·244	0·522
Hemp-stalks,	62·127	4 976	31·501	1·396
Wheat-straw,	61·090	4·365	34·786	0·759
Leaves—poplar-tree,	52·514	4·819	41·289	1·388

In this table considerable difference in the yield of carbon is apparent; but as the samples were prepared by the application of the same temperature, it is evident that the inequality must be owing to a difference in the principles contained in them, and to the greater or less difficulty with which they are decomposed. It must be remembered, however, that the woods themselves do not contain the same amount of carbon. Were the water and ligneous matter the same in all, probably the approximation of the results of analysis would be closer. The quantity of inorganic salts in the various samples is very small, much less so than one might suppose, considering that wood containing about 20 per cent. of moisture gives from one-third to 1 per cent., all of which is retained in the charcoal produced from it, generally amounting to about 20 per cent. The following results obtained by WINKLER are, therefore, more in accordance with what might be expected:—

	Ash Centesimally.
Lime-wood charcoal,	3·55
Maple,	2·27
Ash,	2·27
Elm,	2·17
Willow,	1·50
Fir,	1·44
Pine,	1·38
Poplar,	1·30
Beech,	1·25
Scotch fir-wood,	1·11
Birch,	0·80
Oak,	0·75

Many varieties afford as much as 5 and even 10 per cent. more, especially if the wood has been grown upon silicious soils.

The following analyses of two samples of charcoal prepared by the meiler system, show the quantity of the different ingredients remaining, even after the charring has been carried to its utmost limits:—

	Centesimally represented.	
	Charcoal from Young Oak.	Charcoal from the Aspen.
Carbon,	87·68	87·22
Hydrogen,	2·83	3·20
Oxygen,	6·43	8·72
Ash,	3·06	0·86
	100·00	100·00
Loss by distillation,	13·02	17·07

A remarkable property of charcoal is, that it absorbs with avidity gases and vapours, condensing them within its pores to a most surprising extent (see ACETIC ACID). In consequence of this property, it cannot be exposed to moist air for any length of time, without exerting a hygroscopic action, and assimilating a variable percentage of water, in proportion to the time of exposure and humidity of the atmosphere. From experiments made with freshly prepared charcoal, NAU obtained the subjoined numbers after exposing the samples twenty-four hours to an atmosphere loaded with moisture:—

	Amount of water absorbed in twenty-four hours. Centesimally represented.
White beech charcoal,	0·80
Ash,	4·06
Oak,	4·28
Birch,	4·40
Larch,	4·50
Maple,	4·80
Pine,	5·14
Red beech charcoal,	5·30
Horse-chestnut,	6·06
Elm,	6·60
Alder,	7·93
Scotch fir,	8·20
Willow,	8·20
Italian poplar,	8·50
Fir,	8·90
Black poplar,	16·30

This proportion slowly increases when the exposure is prolonged, as proved by WERLISCH, who found that 100 parts of charcoal, weighed on the 24th of June, became—

On the 30th of June,	104·35
" 7th of July,	105·63
" 16th of July,	106·57
" 29th of July,	107·72
" 20th of August,	108·16
" 17th of September,	108·14

These numbers do not indicate, however, the actual amount of contained moisture, as the charcoal had not been taken immediately from the meiler, so that it might have already absorbed from 3 to 4 parts of water, as the former table shows.

The density of charcoal depends chiefly on that of the wood; hence it is evident that the relative weight of the wood will afford a good idea of the nature of the charcoal produced from it. This fact is of much importance, as the value of the material for fuel may, to a considerable extent, be deduced from its specific gravity. The value of this, for several species of wood, as determined by HASSENFRATZ, is as follows:—

	Specific gravity.
Birch-wood charcoal,	0·203
Ash,	0·200
Wild service wood,	0·196
Red beech,	0·187
White beech,	0·183
Elm,	0·180
Red fir,	0·176
Maple,	0·164
Oak,	0·155
Pear,	0·152
Alder,	0·134
Lime,	0·106

These numbers, however, merely indicate the weight of various samples when the interstices have been filled with air, and, therefore, do not represent the true gravity.

Before proceeding to the other materials which constitute fuel, a few observations may be made on the power of charcoal to conduct heat, and the facility with which it undergoes combustion.

It is a well-known fact that the product resulting from a high temperature, or in other words black charcoal, is a much better conductor of heat than that formed under the influence of a lower heat; it requires also a higher temperature to ignite it; but when this is effected, and an adequate supply of oxygen is kept up, the combustion proceeds steadily, and the heat given off is regular and sustained. Considerable difficulty is found in making accurate determinations of the conducting power of charcoal. The ingenious method of M. VIOLETTE deserves particular notice, as it affords in a simple manner the conducting power of this substance.

Fig. 18.

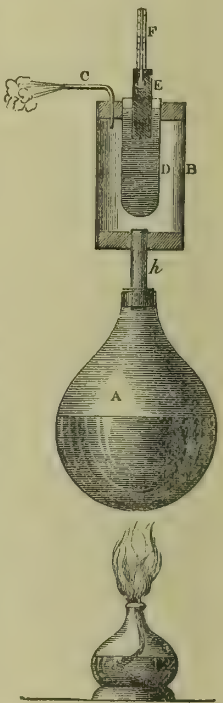


Fig. 18 shows the arrangement of the apparatus, in which A represents a glass flask half filled with water and heated by a lamp; this is connected by means of a glass tube, *h*, with another glass cylinder, B, closed by tightly fitting bungs. In the superior cork or cap of the tube, B, is an opening which receives a third tube, D, nearly filled with mercury, in which is immersed the sample of charcoal, the conducting power of which is to be determined. This is seen in the figure at E, and in its upper end there is made a perforation for the reception of a small mercurial thermometer, F, for the purpose of registering the heat conducted by it. The entire length of the sample, in the experiments made by the inventor of the apparatus, was 0·984 of an inch, of which 0·236 of an inch was immersed in the mercury; 0·195 of an inch of the sample intervened between the latter and the bulb of the thermometer. The source of the heat was the steam circulating in the vessel, B, and escaping through the outlet, C. A portion of the heat of the vapour was abstracted by the mercury, so that it was retained at about 204·8° Fahr.

CONDUCTING POWER OF CHARCOAL OF THE SAME WOOD—BLACK ALDER—PREPARED AT INCREASING TEMPERATURES:—

Temperature.		Indication of the Thermometer.			Conducting power of Charcoal compared with that of Iron represented by 100.
Of the carbonization.		After 5 minutes.	After 10 minutes.	After 15 minutes.	
316° Fahr., ...	27·00	56·00	57·0	57·5	59·5
392 " ...	27·00	57·90	57·5	58·0	60·1
482 " ...	27·00	57·50	57·5	58·0	60·1
572 " ...	27·00	58·00	59·0	59·5	61·6
1873 " ...	26·50	61·00	62·0	62·0	64·2
2282 " ...	26·50	62·00	62·50	63·0	65·2
2732 " ...	26·00	63·00	63·5	64·0	66·3
Charcoal of gas retorts, ...	26·00 22·00	81·00 96·50	82·0 96·5	82·0 96·5	84·7 100·0

The numbers given in the above table were obtained by noting the register of the thermometer at intervals of five minutes till the indication remained stationary: this happened after fifteen minutes' immersion. By employing a bar of iron of the same dimensions as that of the charcoal, and introducing the bulb of the thermometer in a like manner, a comparison was instituted between the charcoal and this substance of known power of conduction.

Regarding the combustion of charcoal, it will be observed, upon taking pieces of it, produced by different modes of working or by unequal degrees of heat—plunging one end of each in the flame of alcohol till ignited, and then allowing it to rest in tranquil air—that very different phenomena will be exhibited in the combustion. The charcoal made at low temperatures, say between 302° and 482° Fahr., burns with a long yellow flame, disengaging large volumes of smoke, and retaining the temperature of combustion for about fifteen minutes, at the end of which time the cylinder will have burned about half an inch. On the other hand, if the wood has been submitted during carbonization to a heat between 482° and 809°, the combustion of the charcoal under the same circumstances is characterized by a clearer flame, which is less fuliginous and persistent, and continues to burn for a longer time, more especially with those samples prepared between 482° and 662°. The charcoal prepared at 809° does not burn so well as any of the samples obtained at a lower heat, nor does the ignition continue so long. When the carbonization is effected at the higher degrees represented in the foregoing table, the cylinder of charcoal, on being introduced into the flame, becomes red-hot like a bar of metal, affording no flame, and is extinguished immediately on withdrawing it, without giving any indication of combustion or leaving a coating of ash. In this last case, the fingers are unable to hold the cylinder whilst its end is in the flame for any length of time, in consequence of the freedom with which it conducts the heat.

All the preceding samples, when reduced to powder, present the same phenomena with respect to combustion as when in solid pieces, only with greater intensity, because, on account of the air interposed, the ignition is easily propagated and maintained. When, however, the experiment is conducted in a very tranquil atmosphere, the burning ceases after a part is consumed. This effect must doubtless be owing to the carbonic acid, which, being heavier than common air, does not ascend with sufficient freedom to permit the oxygen of the latter to come in contact with the burning matter.

In many manufactories where this article is required in powder, great care must be exercised, as it often happens that spontaneous combustion takes place. The most inflammable charcoals take fire at 572°, and those that are prepared at the latter heat invariably ignite at a temperature varying from 680° to 716°, according to the nature of the wood. Charcoal from light and porous woods always burns more freely than that obtained from the hard and dense kinds.

Peat.—Another species of fuel, much employed for domestic purposes as well as for many manufactures, in which it has lately found admittance, is *peat.* Such is the name by which the brownish-black spongy substance, found in almost every country, filling up cavities, and constituting what is termed *bog*, is known. It is a product of vegetable origin, but differing from wood as well in the nature of the growth as from the change which it has undergone atomically through the combined agency of time and pressure. It was once supposed that this formation was, in point of time, coeval with the disposition of the face of the country into hills and valleys; by some it was considered a bituminous deposit from the sea, the wreck of floating islands previous to the great convulsions which the earth underwent during the formation of the present continents and islands. By others it was even regarded as an organic substance in a state of vitality, and actually growing. From examining its structure it has been found that it is constituted of vegetable matters, generally mosses and species of aquatic plants in different stages of decomposition.

The extent and depth of the peat-bogs vary considerably in the different countries where they are found, and depend on circumstances quite distinct from each other. It is evident that the area which they may occupy is intimately connected with the distribution of the water, from whatever causes. In Holland and North Germany the water of the ocean seems to have largely contributed to the moisture in which they originated. The peat-moors of the Grand-duchy of Hesse would appear to be occasioned by the overflow of the Rhine, whereby these tracts were irrigated, and the waters remaining, and necessarily becoming stagnant, the place was soon changed, and instead of remaining a swampy district, it ultimately became a morass. On the other hand, the thickness of the beds of peat seems, from repeated observation, to be dependent upon the nature of the subsoil. Where the bottom is quartzose, the deposit is invariably not very thick; but if it be such as yields by disintegration a clayey coating, the depth and extent are much more considerable. The morasses of Holland are to a considerable extent about 6 feet in depth, as are likewise those in upland situations; whilst many of the peat bogs in Ireland are from 30 to 40 feet in depth. On intersecting these, it appears from the fact of layers of gravel, clay, and shells, being interposed horizontally, that these tracts have been swept over with violent currents of water; such layers, however, are never more than a few feet in thickness, and seem to have retained all the conditions favourable for the growth of the plants conducive to the formation of peat.

From its physical constitution, this substance may be regarded as a kind of fossil fuel, and undoubtedly it is one of the most extensive sources known. Viewing it as the product of the decomposition of plants carried on through a long succession of ages up to the present, it is natural to expect that when cut vertically differences should appear showing the advancing state of decomposition. In every instance, almost, this progressive change is exhibited, and, consequently, peat is classed into—

Recent Peat and *Older Peat*, from the appearance it presents. The former bears distinctive traces of its origin in the roots, leaves, and stems of plants, the structure of which is still retained. It is very porous, tough, and elastic in some tracts; but in others, especially where the bog is well drained, very brittle. The colour varies, with the age and the progress of the decomposition, from a light to a blackish brown. In the second, to which the preceding gradually inclines, no traces of fibrous matters—such as roots, stems, or leaves—are observed, but it presents when cut a pitchy shining hue, and is dense and fine in the grain. Preference has always been acceded to this as a fuel from its superior gravity, and the greater heat which it produces when undergoing combustion. From the change which the vegetables pass through, it is evident that the usual process of putrefaction is carried on in the ordinary way at the commencement; but as the surface grows, and contact with the air is cut off, the mass is left to the play of the affinity of its elements, rendered more active by the pressure which it has to sustain. The alteration is attended with the evolution of marsh gas—bihydride of carbon, CH_4—and carbonic acid, in the same way as in every case of partial destructive distillation; but from the excess of moisture present it is evident that this action cannot, in the case of peat, be so complete as in coal, which is analogous in nature. Many bodies are detected in peat, however, which are not contained in coal, although the ultimate elements of both are the same. SPRENGEL detected in peat considerable quantities of ulmic acid—known also by the names *ulmin*, *humus*, *gein*, and *geic acid*—the composition of which, as obtained from turf, is expressed by the formula $C_{40}H_{15}O_{12}N$; and when procured from mould, by $C_{40}H_{15}O_{14}N$. This principle is dissolved out by alkalies, and precipitated from their solutions by acids in brownish flakes; this, however, as also the other varieties of resins examined by MULDER, are of little use hitherto in the arts.

The density of peat varies with the relative position in which it is found, with the thickness of the stratum, and the amount of mineral matters which it contains. Freshly cut, it is saturated with water to the extent of 80 to 90 per cent. in some cases, and, when subjected to the ordinary process of air-drying, it retains a large quantity of this, amounting sometimes to 30 per cent.

The estimation of the gravity in this state would lead only to relative approximations, even if the percentage of moisture was known, and the species examined had undergone about the same degree of decomposition. As already intimated, however, the latter principally determines the difference of specific weight in peat from the same cutting. KARMARSH arrived at the following results with regard to Hanoverian peat:—

Species.	Specific gravity.
1. Light-coloured young grass peat, nearly unchanged moss, ...	0·113 to 0·263
2. Young brownish black peat—an earthy matrix intersected with roots,........	0·240 to 0·600
3. Old earthy peat without any fibrous texture,	0·564 to 0·902
4. Old or pitch peat,......................	0·639 to 1·039

From the results of the ultimate analysis of dried peat, it is observed that the numbers which are found do not correspond with the analysis of dried wood. The following analyses by REGNAULT and MULDER show the centesimal contents of carbon, hydrogen, and oxygen:—

Locality.	Carbon.	Hydrogen.	Oxygen.	
Vulcaire,..........	59·57	5·96	34·47	Regnault.
	60·40	5·86	33·64	Mulder.
Long,..............	60·06	6·21	33·73	Regnault.
	60·89	6·21	32·90	Mulder.
Champ de Feu,....	60·21 ...	6·45 ...	33·34	Regnault.
	61·05	6·45	32·50	Mulder.
Friesland,.........	59·42	5·87	34·71	"
Friesland,.........	60 41	5·87	34·02	"
Holland,..........	59·27	5·41	35·35	"

Comparing these numbers with those afforded by dry wood, it would appear—viewing the peat as a compound of equal weights of water and carbon, and supposing that the oxygen in the wood is proportioned to the hydrogen to form water—that an excess of 10 per cent. of carbon and 2 per cent. of hydrogen is contained in the peat over the quantity of these elements which wood affords, but the amount of water is reduced 10 per cent. This difference in the centesimal amount of the elements might have arisen from the decomposition which the matter of the peat has undergone.

Peat always contains earthy matters in greater or less proportion according to the thickness of the stratum and its position. Surface-peat generally contains less mineral matters than the second strata, which often possesses so much of these as to render it useless in point of economy as fuel. In this, as well as from the nature of those matters, it essentially differs from wood. These substances are left when the peat is consumed in contact with air in the form of ash, and from the nature of the ingredients it presents various appearances from white to grey and ochrey.

In some varieties no less than one-third of the entire weight consists of incombustible substances, which, it is needless to say, is too large a quantity, and prevents their being much employed as a source of heat. Such varieties are, however, valuable as manures, owing to their containing a large amount of phosphates and other salts, that serve to enrich the soil.

Peat, when distilled in close vessels, gives off various products similar to those which wood affords, besides ammonia and some bodies of a fatty nature, which are much in demand in many departments of the industrial arts. In its natural state it is highly antiseptic, to which may be attributed the long period which is required before the traces of the substances originating it are effaced. This quality has been further proved by the wood which is found without being in the least injured, although buried 30 feet deep in it for centuries. Not only these, but human bodies and remains of animals—the latter now extinct—and other substances prone to putrefaction, have been found at a great depth in a high state of preservation.

For domestic purposes peat is prepared by a very simple course of operations, differing sometimes according to its nature and thickness.

In every case the surface layer, which contains the living plants and their roots in the natural state, is stripped off to the depth of 6 to 9 or 12 inches. The material is then cut with a kind of spade known as the *slane*, which has a wing bent at right angles to the blade of the instrument, so as to form with the latter two sides of a square. Sometimes two such wings or ears are added to the tool, and at the outer end these are united by a plate of iron which gives to it the appearance of a hollow rectangular cube, open at both ends. By this instrument the peat is cut in long square masses, and then spread upon the sward, where it spontaneously loses its water. After the bricks have acquired sufficient consistency, they are piled up on end so as to afford a more thorough exposure to the air; and finally, when desiccation has advanced, the turf, as it is then called, is piled together, being built round by a kind of clamp construction of the sods or bricks, and left till the material becomes as dry as it can be made by exposure to the air. Such is the mode adopted when the peat is sufficiently elastic to bear being so handled without breaking; when, however, the material is brittle and will not admit of being used in this way, it is dug out with ordinary spades and shovels, and all roots, stones, and such like solid bodies picked out. It is then spread in a layer of from 12 to 18 inches in thickness, watered, and brought to a homogeneous mixture, either by the tramping of men or beasts, where the latter can be employed. Afterwards the surface is smoothed and moulded in forms, either with the hand or a small mould which indents the surface. When the excess of water has drained off and the peat becomes consistent, the bricks are cut out with a long knife, and dried in the manner already indicated. In many moors or fens the peat is so surcharged with water that it cannot be extracted even with the spade; in this case the workmen employ a kind of dredge, by which the material is collected. It is deposited on a sloping sward, and after the superabundance of water has drained off and the mass becomes more consistent, it is moulded into bricks. The latter processes are usually resorted to in France, Germany, and most other localities where peat abounds. In Holland a different course is pursued, which, though more circuitous, is notwithstanding more effectual in producing a denser fuel than can be obtained by the foregoing methods. The upper stratum, which is light and fibrous in its nature, is nearly always moulded with the slane, though sometimes it is subjected to the same operations as the under layer. Generally, this is scooped out with a kind of ladle when it is not too wet, and carried to the tempering ground; where, by sprinkling with water, tramping with the feet, and tempering with a rake, it is brought to a homogeneous consistence and freed from stones, bits of wood, leaves, and the like. In case the matter is slimy, and so thin that it will not admit of adhering together in masses, another kind of tool is employed, enabling much more peat to be abstracted with less water, than if the ordinary iron ladle dredge were used. It consists of a ring of iron, the edge of which is sharp, attached to a long handle; the side of this band is perforated for the purpose of affixing the body, which is a thick cloth, and the whole forms an instrument not unlike a fisherman's landing-net. Much more peat is taken up by this, and the excess of water filtering through the meshes of the tool, the peat is in a state which will admit of being immediately worked. This very slimy material is kneaded in a kind of trough or tub, till it becomes thoroughly blended together. In this state it appears like a kind of mortar. The next operation is to prepare the sward on which it is to be spread. This is done by laying upon it a covering of hay, which is trodden down to a level, whereon the peat is spread to the depth of a foot or more. The depth is regulated by means of planks or boards set in parallel lines, and placed, as circumstances may admit, from 12 to 30 feet apart. It is usual to beat down the surface of these beds to give the peat an uniform thickness. After a few days, when the excess of water has, partly by draining off, partly by infiltrating into the soil, and partly by evaporating, disappeared, and the layer of matter has acquired a certain consistence, it is rendered more compact by treading. This part of the work is performed by women and children, who attach flat boards, about 6 inches broad and 12 to 14 long, to their feet. Before this treading is finished the peat has acquired such solidity that it will bear a person's weight upon it without sinking. The surface is again brought to a level by beating it with oars, shovels, and the like; and after this is accomplished, the surface is divided into squares, the sides of which are about 4 to 5 inches. When the tracings thus made are cut, the bricks are about 8 inches long by 4 to 5 inches square in the section. The drying is performed by placing alternate rows crosswise upon one another, reversing this order in a few days, and continuing the exposure till the most of the moisture has disappeared. When this is the case the turf is stored for use, but it is necessary that the moisture be sufficiently expelled before this part of the business is performed, as, according to DUMAS, when this is not effected the stacks are liable to a fermentative process, which raises the temperature so high as often to cause spontaneous combustion. It has been already stated that one essential quality of peat, in relation to its value as a fuel, is its density and freedom from large quantities of mineral matters; but another is also required, namely, that it contain as little water as possible. However well exposed or prepared, air-dried peat always retains from 20 to 30 per cent. of moisture, and this expends a considerable quantity of the heat of combustion in its evaporation. When intended for particular purposes, such as for charring in heaps, for lime-burning, and such like purpose where it is to be piled up in large masses, or has to resist much pressure, the value of the material is enhanced by the quality of strength or solidity, because, if it were very brittle, it would prove almost valueless for either of these uses.

Compression of Peat.—The relative heating power of dense peat well dried is about the same as wood, and half that of coal; the lighter kinds prove to be not more than one-third as effectual as coal for heating. Prepared according to the improved processes which have lately been introduced, it gains considerably in heating power, as much more combustible material is contained in compressed peat, bulk for bulk, than in the ordinary sods or moulded turf. Much difficulty, however, stands in the way of effecting this condensation of the article, owing to the elastic nature of the fibre, which causes a distention after the force is removed. The system of pressing each sod or mould, as in the preparation of artificial fuels, would never answer with peat, as the labour would be too great in proportion to the value of the material; and, besides, the supply which could be so furnished would be inadequate to the demands of a large consumption. One method that has been proposed is the adoption of powerful hydraulic presses, which, while they are able to overcome the elasticity of the material, can supply it in considerable abundance. The manner of compressing was to break up the fibre of the peat as much as possible after cutting, and then to place it, interlaid with coarse cloths or cocoa-nut matting, under the machine. After the action had been exerted during the period allowed, the material was found to be reduced to one-third its original volume, and to have lost about two-fifths of its weight. In this state the peat, when thoroughly dried, is not so hygroscopic as when the drying is conducted in the open air and no pressure exerted, and the lighter kinds yield by compression a substance denser than wood; the lower stratum affords a product still more so. The elimination of the water by pressure improves the quality of the peat in other respects, not the least of which is the reduction of the relative amount of mineral waters contained in it, for considerable quantities are carried off in the water that would remain if it were exposed to spontaneous exsiccation. Another method is to convert the peat into a magma, with the addition of water if necessary, and when by means of *centrifugal* power this is subsequently got rid of, a very dense product is obtained. Again, it has been recommended to use a box divided into a number of compartments suited to the size of the machine, and pressure to be exerted upon this by rollers adapted to one another by means of leverages.

When peat is subjected to destructive distillation, ammonia is invariably one of the products, a circumstance for which it was difficult to account, until it was shown by Sprengel that ulmin is not, as was formerly supposed, devoid of nitrogen. Moreover, during the decomposition of turf, nitrogen may be assimilated from the air, just in the same manner as decaying wood or vegetable matter takes it up.

When peat is exposed to the action of heat in close vessels, it affords a variety of substances, the principal being pyroligneous acid; a brown empyreumatic crystallizable oil, from which numerous products may be extracted, and among them paraffin; carbonic oxide and carbonic acid, hydrocarbon gases, together with a variable quantity of ammonia.

The high heating power of peat-charcoal, as well as its disinfecting and other qualities, invest it with peculiar interest to the smelter, the sanitary reformer, and the agriculturist; for the former it has long been productive of great advantages, more especially in the manufacture of iron, and therefore its production, on the most economical scale and in the largest quantity, has been a subject to which some attention has been paid. This is more particularly the case in Bohemia, Bavaria, France, Russia, and other countries, where it is used in the blast-furnaces of their iron-smelting establishments, and produces very satisfactory results. In the numerous other processes to which the metal is subjected, the charcoal is found quite as efficient, if not more so, than wood-charcoal.

When peat is acted upon by heat in close vessels, it yields a variable amount of charcoal, from 25 to 40 per cent., according to its density and state of dryness; but as it is rarely distilled in this way, the quantity obtained is from 25 to 30 per cent., and at best does not exceed 35 per cent. The methods followed for the charring of peat are, in some respects, similar to those already described as being pursued in carbonizing wood on the large scale; these are the meiler system, and that by the furnace. For operations by the first of these methods, the nature of the peat and the regular form of the sods or bricks offer advantages for constructing the heap more regularly, leaving less interstitial space than the logs of wood; and being less combustible than the latter, the process does not exact that minute attention which the carbonization of wood requires. It is necessary that the peat should be thoroughly desiccated, otherwise the charring will proceed irregularly, and sometimes not at all. Large quantities of peat are carbonized in this way in the Vosges, in Bavaria, Saxony, and Bohemia. In these places, one or other of two forms of constructing the meiler is adopted—either the circular or bee-hive, so frequently resorted to in charring wood, or the rectangular one. At the Royal Iron Works of Weierhammer, in Bavaria, where the refining and puddling of iron has been carried on since 1838 by means of peat-charcoal, the peat is charred in the circular mound, prepared almost as in manufacturing wood-charcoal.

A level site being chosen, a stake or quandel is fixed in the middle of a circular space, and round it on the ground a quantity of brushwood is spread, and which in turn is covered with waste charcoal from a previous operation. The turf is then piled round to the extent of the base, and to the proper height, preserving the conical shape. Generally, the size of the heap is about 2500 cubic feet, or $13\frac{1}{2}$ tons of the peat of the locality. When the central stake is withdrawn, brushwood is introduced into the opening and ignited. This communicates fire to the surrounding mass, which, in turn, conveys the heat towards the exterior. Owing to the closeness with which the turf admits of being packed together, the carbonization would proceed but slowly, were it not that air-channels of the breadth of a single brick of the peat are constructed at regular distances, and radiating to the circumference of the meiler. A covering of moss and leaves is placed upon the body of the heap, and outside this another of sand and turf ashes, or charcoal dust, is thrown on, leaving the upper part open, as a kind of chimney for the passage of the gaseous products, till the mass has been thoroughly ignited. As soon as flame appears at the top of the heap, a covering is thrown on, and the contraction of the mass observed, so as to keep any breaks occasioned by the sinking renovated. The charring is conducted regularly in the whole meiler by closing the draught-holes at the base, where the combustion becomes too vivid, or boring a few about a foot asunder in the upper part, where the progress is slack. Twelve to fourteen days are necessary to char and cool a meiler of the above size, so as to be fit for removal. About 700 cubic feet of charcoal are obtained, weighing about 3 tons 8 cwts., or 27·7 per cent.; hence, somewhat less than 4 tons of the peat of the district yields 1 ton of charcoal.

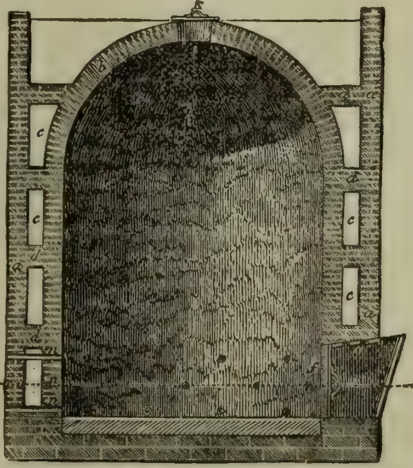
In Saxony the rick or rectangular system is adopted, and the results are good. The ground is levelled and covered with sand in the usual way, and afterwards the rectangular space marked out; this is about 50 feet long by 5 or 6 in breadth. The middle of this plot is hollowed out into a kind of basin, and from it two channels or drains are cut from the ends of the intended heap, but inclining towards the central cavity, Both channels and well are constructed of, or are lined with bricks, a layer of clay being laid beneath, so as to prevent any fluid products collecting therein from percolating through the soil. A small gutter leads from the cavity in the middle to a tank at a little distance, where the liquids are recovered. These necessary constructions being made, a number of quandels is fixed in the longitudinal channel, 10 feet apart, and the peat heap constructed to the height of 4 feet, leaving transverse channels corresponding with the vertical one which the stake forms. When finished, the quandels are withdrawn, and the whole coated with a mixture of clay, sand, and chopped straw or grass, the latter being used to prevent the luting from cracking. This mixture is prepared in two boxes or pits, one at each side of the mound, and quantities of it are always at hand so as to be available for stopping any cracks which might present themselves during the charring. Ignition is commenced at each end of the rhomboid by a fire placed in the central channel; the brushwood with which this has been filled burns, and in doing so sets fire to the surrounding peat. When the turf is fully ignited throughout the whole mass, a thick black smoke issues from the chimneys; as the carbonization proceeds, this becomes lighter, assuming gradually a greyish-white colour, and finally changes to a bluish shade as the moisture evaporates. At this stage sulphurous acid becomes disengaged. As soon as the whole of the moisture is dispelled—a fact ascertained by holding the hand in the vapour as it issues from the chimneys, and observing if condensation takes place—the fire is gradually smothered by closing the air channels and fire flues. Care is also required in the management of the draught, so as not to allow of a consumption of charcoal taking place; generally, the apertures on the windward side are kept closed, the opposite ones being sufficient to supply air. The charcoal prepared in this way is of excellent quality, and much used in the metallurgical establishments of Saxony and Bohemia.

Both these systems of charring peat afford nearly the same yield of charcoal, when the operations have been properly attended to. It ranges from 24 per cent. by weight, and 27 by bulk when the peat is not thoroughly air-dried; but if this condition has been attained, the product is about 27 per cent. by weight, or 32½ by bulk; a larger produce is occasionally obtained, but in those cases the exception must be attributed to the density and dryness of the material before carbonization.

Partly from the fact that less labour is required in managing the operation, whilst a regularity in the produce is, in some measure, insured, and partly from the circumstance that there always exists a supply of material at hand in every peat district, which would render the expense of removal of furnaces unnecessary when once erected, the system of charring in kilns has been resorted to with advantage. Furnaces or kilns are employed near Meaux in France, in East Friesland, and Bohemia, to a considerable extent.

The furnace or kiln employed for this purpose at Oberndorf, in Wurtemburg, is represented in Fig. 19. It consists of an upright cylinder, capable of distilling about four tons of average peat; the top is closed by an arch, with the exception of an opening, *i*, through which the peat is introduced; it also answers the purpose of a chimney till the charge is carbonized. A double line of construction is adopted in the erection of these kilns; an inner one, *b b*, of firebrick, and an outer one, *a a*, of more common

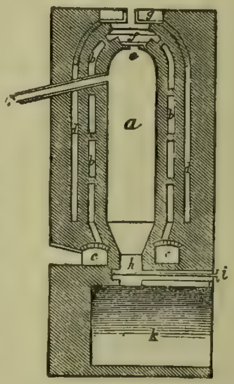
Fig. 19.



material: both are about 15 inches thick, and between them is an interstice, *c c*, of the same width, excepting where the brickwork extends the whole breadth, as at *d d*, for giving greater firmness to the construction. The superior aperture, *i*, is closed by a tightly-fitting lid, *k*, when necessary; at the base is another door, closed by a cast-iron plate, *f*; and behind this is a space, *m*, formed by the door and the plate or board, *e*, and which is filled with sand through the aperture, *g*; thus the draught is effectually cut off at this orifice. There are three tiers of holes, *d d d*, formed at a short distance from the base of the furnace, through which air enters for supporting the combustion of the peat during the carbonization, as long as this takes place. In working this kiln the peat is thrown in at the top and packed closely, with the exception of a few channels left free, corresponding to the lower draught holes, and also a vacant space in the centre; after being filled, fire is thrown in from the top, and the orifice in this part left open; when the fire has spread through the mass, so as to present a glowing appearance on being viewed through the lower apertures, these are closed with clay stoppers, and the combustion allowed to proceed till the same appearance is observed on looking through the second holes, when these are likewise stopped; and when the mass appears white hot at the third row of perforations, and no more smoke appears, all the apertures are secured, and the mass is allowed to remain till cold. Forty-eight hours are occupied in bringing the mass to incandescence, and after that seven or eight days are required for the cooling of the furnace. To avoid this delay, it is customary to have a damper plate situated in the bottom of the furnace, under which is a pit, so that on withdrawing the damper, the red-hot charcoal falls into the pit, and the furnace is ready for a fresh charge. Sometimes the furnace is so constructed as to enable the manufacturer to recover some of the products of distillation, and use the combustible products for heating the mass of peat. In these, a pipe leads from the shoulder of the arch to a kind of condenser, where the ammoniacal and tarry matters are retained, and the gaseous bodies are reconducted by pipes to the bottom of the furnace, where they are burned under a grating, and serve to ignite the charge. No delay, or at most only an inconsiderable one, takes place in the charring with the latter kind of furnace, and the product is satisfactory in relation to quality and yield.

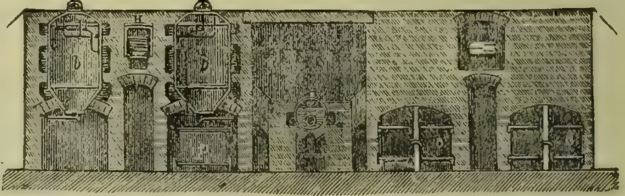
Of this description are the kilns used at Crouy-sur-l'Ourcq, near Meaux, one of which is represented in Fig. 20. In this kiln the carbonization is effected in a cylinder, *a*, heated exteriorly by the flame and heat from the fires, *c c*, which circulate in the spiral flue, *b b*; *d d* is a chamber encircling the walls of the flue, wherein air is confined, with the view of retaining and equalizing the heat. The peat is introduced into the kiln by the aperture, *e*, at the top; this aperture is closed when the charring is going on, by an iron plate, *f*; the products of the combustion going on in the fires, *c c*, issue by an opening, *g*, in the top, and those of the distillation of the charge by a pipe, *l*, connected with a condensing apparatus of the usual construction, and in which liquid products are retained, the uncondensed gas being conveyed back to the fires, where by their combustion they serve, in part, to maintain the proper degree of heat. When the carbonization is completed, the charcoal is removed by the channel, *h*, by drawing the plate, *i*, which serves as the bottom of the kilns; it then falls into the chamber, where it is allowed to cool; from 35 to 40 per cent. of charcoal is obtained, according to the density and state of dryness of the the crude fuel. The cost of charring by this furnace is estimated at an average of 4*s*. per ton of charcoal.

Fig. 20.



Vignoles has taken out a patent for drying, compressing, and carbonizing peat, the latter being effected by means of steam heated to 450° or 460° Fahr., and the two former by a hydro-extractor, in which the centrifugal force expels the water, and renders the mass denser at the same time. With reference to the charring—the peat dried in the air, or by a current of heated gases forced through a chamber containing it, is thrown into cylindrical vessels, into which steam at a high temperature is forced, till the charring is effected. Fig. 21 shows a vertical section and partial elevation of the apparatus. In this, *a* represents a section of the boiler employed for raising the steam; it is placed over furnace, the flues of which, after passing under the boiler, branch off and circulate round the carbonizing cylinders, and finally enter the chimney. Two of the charring cylinders are shown at *b b*, of which there are six at each side of the boiler; they are ranged round a coil of piping, H, in which the steam from the boiler is heated to the required degree by a fire, previous to its passing into the cylinders where the peat is charred, by means of pipes connecting them. After the steam traverses one of these carbonizers it escapes by a pipe, which conducts it over the furnace, to raise its temperature previous to its passage through the next carbonizer in the series. In this way the steam, being first heated, is made to traverse a carbonizing vessel

Fig. 21.



and the heating pipe successively, till it passes through the whole of the charring vessels. Ultimately the waste steam is made to work a low-pressure engine, which turns a fan that forces air, heated by pipes placed in a furnace to 250°, into the drying chamber where the peat is desiccated.

The carbonizers, as may be inferred from the drawing, are conical towards the bottom, and are furnished with a valve or door which is rendered steam-tight, but may be opened when the charring is completed, so as to allow the charcoal to fall into a box, *p*, beneath it, and into which low pressure steam is passed for the purpose of cooling the charcoal. These boxes are constructed of iron, and are well covered, lest the charcoal might spontaneously ignite, to which it is liable if exposed to air at this temperature; they move on tramways, and can be drawn out when required through the door-ways, *c c*. The top of the cylinder has a similar opening secured by a screw; through this aperture the charge of peat is introduced.

We now proceed to notice briefly the chief recent methods of getting and utilizing peat. The following is an abstract of a paper in the "Proceedings of the Institution of Civil Engineers," vol. xxxviii., entitled, "Peat Fuel Machinery," by J. McCarthy Meadows:—

"The several systems of machinery for macerating and pressing peat, at present in use, can be conveniently divided into two classes, which, for distinction and brevity, may be called the wet process and the dry process.

"The wet process comprises all methods for making dense turf, in which peat, in its natural condition, is macerated or mixed so as to form a pulp, either without or with the addition of water.

"The dry process includes the compression, by mechanical force, of peat in a dry, powdery condition, and is represented by the system of Exter for making compressed turf.

"In the wet process the pugmill principle was first applied for tearing and mixing peat. It was introduced in Bavaria by Weber, within the last twenty years; and the modes of arranging the blades upon the upright shaft, and of forcing the peat pulp from the mill under a moderate pressure, have been since that time the principal objects of improvement. In other respects there has not been any material departure, in external form, from ordinary types of pugmill machinery.

"Different arrangements of the blades and of the forcing or squeezing action have been introduced, and will be illustrated by reference to examples of the best modern German, Dutch, and English machinery for the wet process.

"Of the German machines, that made by Schlickeysen offers one principle of construction. The mill is, in general, from 5 feet to 6 feet in height, with a diameter of about 2½ feet at the top, slightly decreasing downwards. In this system the blades on the upright shaft are arranged as an irregular spiral, which combines a downward forcing or squeezing action with that of tearing and mixing the peat. The peat is thus not only made into pulp, but in that condition is forced outwards through holes or dies (usually from 3 to 4 inches square), in one or more mouth-pieces, at the sides near the bottom of the machine. As the pulp issues it is cut into short lengths, and removed on boards for drying.

"In the Dutch machine by Rahder, the operations of tearing the peat and of forcing it from the mill are performed by distinct portions of the mechanism. The mill itself is about 6 feet in height and nearly 3 feet in diameter at the top. In the upper part of this machine the arms or blades on the upright shaft simply tear and mix the peat. The pulp thus made sinks to a chamber or space in the bottom of the mill, over which space the foot of the upright shaft is carried by an iron bridging piece. This lower chamber is therefore not occupied by the shaft; at the same time it is in open communication with the body of the mill except where it is crossed by the bridge-bar for carrying the shaft. In this chamber a short horizontal spiral or screw forces the peat pulp outwards, and in so doing subjects it to a mixing action. In this arrangement there is but one mouth-piece, placed 2 feet from the side of the machine, to which it is connected by a taper matching piece. The spiral or screw, therefore, constantly works against a mass of pulp which is being steadily moved, under pressure, through the taper matching piece, to the holes or dies in the mouth-piece. This spiral is from 2 feet to 2½ feet in length, and about 1 foot in diameter.

"In connection with the twofold action of the Dutch machine, a third mechanical arrangement may be adopted, in which, for a better comminution of the peat, the action of a horizontal screw or spiral is mainly relied on, in combination with fixed cutters in the inside of the casing. The peat machine of Messrs. Clayton, of London, consists, in principle, essentially on these conditions.

"It is submitted that, for general purposes, a rough, effective tearing and mixing of peat in the natural condition, with a moderate pressure to give body to the pulp, are sufficient for the making of good dense turf; and that any elaboration of mechanism, with a view to a more perfect comminution of the peat, is not attended with the benefits which might be expected, or which are sometimes claimed for it.

"To the pugmill class belongs also Eichorn's system of Kugeltorf, or 'ball turf' manufacture, which has the merit of originality of arrangement for the making and drying of this kind of turf. In this system the peat is, in the first instance, roughly torn or mixed before being raised by elevators to an upper working floor to supply small pugmills.

"It is evident that the objects of Eichorn consisted more in efforts to solve the difficulties of drying the peat, by a system designed for working during the greater portion of each year, independently of the weather, than in any marked improvements in the macerating or mixing of the peat itself. And it is submitted that where a daily production of peat extending over seven or eight months of the year is to be realized, the task of the engineer largely lies in connection with effective, and at the same time economical, arrangements for drying.

"In contrast with EICHORN'S system in this respect, the arrangement introduced by the Messrs. CLAYTON may be referred to. For each machine, the daily work of which is claimed to be equal to form 15 to 20 tons of dense turf when in air-dried state, 9000 wooden trays were, in 1873, stated to be needed to keep the work fairly going, one day with another, in addition to the racks and sheds necessary for the reception of these trays. In the former there is the principle of fixed lattice frames, and in the latter that of numerous portable wooden trays for drying.

"As far as the subject has now been treated, it may be assumed that the peat is operated upon as it comes from the bog without the addition of water, except in rare cases where, owing to exceptional dryness, water may be required to reduce the pulp to the same consistence with that given by peat containing the average percentage of 80 per cent. of water.

"In the French system of CHALLETON, however, water is copiously added, so as to reduce the peat into a fluid condition. In that state it is pumped up to a staging, where it undergoes filtering for the removal of the grosser portions, and the residuum flows by shoots into shallow settling and drying basins. These are provided in the bottom with arrangements for filterage and drainage; and the peat, when sufficiently firm, is cut into pieces for drying. A fine dense peat is obtained in this manner; but the system is not favourable to large production, and can hardly be held to be an improvement in this respect upon those already mentioned. The large extent of reservoirs necessary for producing even moderate quantities limits the capability of useful economic production; and unless these reservoirs be protected by roofs from the weather, the period during which they could be advantageously used would be, in these countries, limited to a few months in each year. Assuming these reservoirs to be covered over with a view to a lengthened period of working during each year, drying sheds would likewise be necessary. This system would therefore require more erections, to enable the working period to be extended over seven or eight months yearly, than any of those already described.

"The dry process, which is mainly the German system of EXTER, and the only one in which, upon anything like an important scale, density in turf is effected by mechanical force. The peat in this system is, in the first instance, obtained in a fine or powdery state from the surface of the bog. This is effected by a thin horizontal slicing of the surface. The layers or slices break up at once before the action of the surface ploughs which are used for the purpose; and the peat is collected into heaps, and partially dried upon the bog. It is then removed to a capacious shed, covered by a roof, but for the greater part open at the sides, where the drying still further proceeds by ordinary evaporation. As the period during which the manufacture can be carried on continuously depends on the quantity of fine peat obtainable in favourable weather, the getting of this material in sufficient quantity forms the special out-door work upon this system, during the months that admit of its collection and storage in a partially dry condition.

"The covered storage sheds, to contain the fine peat in the condition already mentioned, are in immediate connection with the peat factory. According as it is required for use the peat is first subjected to a sifting process for the removal of the coarser portions, and after passing through the sieves it is raised to the upper part of an inclosed chamber in which are wrought-iron drying tables, one over another, heated by the exhaust steam from the engine of the works. Upon each of the drying tables spirals are arranged lengthways, all driven by gearing at the back, which constantly keep the peat powder turned over, and exposed uniformly to the heat as it is moved forward. In its course the peat falls from one table to another, until the openings in the lower part of the chamber are reached, through which, at a temperature of from 120° to 130° Fahr., and with still a considerable proportion of warm diffused moisture, it falls into the cylinders in which it is compressed. The compression is effected by iron rams or plungers actuated by powerful eccentrics, fixed upon the main shaft of the engine of the factory. The cylinders for compression are fixed horizontally, and are open from end to end; the resistance against which the rams work at each stroke being formed by a portion of the compressed turf previously made which remains in the cylinder. At each stroke the mass of compressed turf is moved forward, and its friction is the measure of resistance necessary for mechanically adding to the turf already compressed the portion of fine peat which, at every stroke of the ram, is converted into compressed turf. From the back of these cylinders wooden shoots conduct the compressed turf in continuous lengths to the place for its delivery. It may travel from 15 to 20 feet in this manner, and as it passes beyond the shoots it breaks off at the overhang by its own weight, into pieces varying from 9 inches to 12 inches, or thereabouts, in length, which fall ready at once for use.

"The advantages of this system may be summed up in the drying of the peat in detail—in the condition most favourable for the purpose in the open air—and in the practicability of carrying on the manufacture nearly all the year round, within doors, if sufficient fine material be obtained and stored during the months in which such work can be done. The drawbacks are, mainly, the outlay necessary for such an erection, the wear and tear of the mechanism, and the high rate of the cost of production. Turf prepared in this manner is more adapted for use in furnaces with strong draught than for domestic purposes."

In the discussion which followed the reading of this paper, Mr. M'DONNELL remarked that he thought the best method by which peat could be used with advantage was in a SIEMENS' gas furnace. In trials last year, in forging iron, he found that 1 ton of finished forgings required 4·96 tons of coal in an ordinary air furnace; while the same quantity of iron was forged with 5·09 tons of peat, or 2·86 tons of rather small Welsh steam coal, in a SIEMENS' gas furnace. In the case of the gas furnace the loss in the iron was from 5 to 6 per cent. less than when the iron was heated in an air furnace.

A method of getting and preparing peat by means of floating machinery has been proposed by Mr. HODGES, and has been carried out by the Canada Peat Fuel Company, under the management of Mr. DAVID AIKMAN. A floating machine consists of a barge with excavator and machinery on board. On the bow are a pair of large augers, which work inside a casing and cut a depth of 6 feet and a length of 2 inches at each revolution, but this is of course influenced by the nature of the peat. The peat is received on board, where it undergoes various operations, such as the removal of sticks by a stick-catcher, and becomes pulped into a homogeneous semi-liquid mass, which drops out through port-holes in the stern on a bed previously prepared. This is spread evenly by men, about 8 inches deep and 120 feet wide, previously prepared drains carrying off the liquid which filters away; the mass gets firm enough at the end of a day for the whole to be scored over in lines 5 inches apart. As soon as the pulp is solid enough to bear men standing on boards longitudinal cuts are made. At the end of a fortnight these cuts open, and the whole presents the appearance of a floor of bricks 18 inches by 5 inches. As soon as these are hard enough to handle they are removed by boys and placed on drying racks, where they remain till dry.

COAL.—This is by far the most valuable and extensively disseminated fuel, or source of heat, and is defined by REDFERN, *a compressed and chemically altered vegetable matter, associated with more or less earthy substances, and capable of being used as fuel.* This definition expresses all that is necessary, but its truth can only be established by the concurrence and aid of several branches of knowledge. For instance, *animal* matters may, by a process of decomposition, yield a mass of carbonaceous substances which could not be distinguished from similar vegetable ones by the naked eye. In such cases the microscope and chemical analysis lead to a certainty as to the nature of the originals; the former by revealing the texture of the fibrous nature of the plant, and the latter by the separation and estimation of those bodies into which it has been partly resolved.

Evidences of the origin and character of coal may be gathered from the geological position of the deposit, the mineral characteristics, the chemical nature, and the visual appearance of the substance under high magnifying power. It is the opinion of geologists that coal may be viewed as stratified rock, in which layers of other geological formations, such as clays, sandstones, and limestones, are found. These in themselves form vast deposits or strata; but in this respect there is no difference between them and the coal beds, excepting in the nature of the substances. How the matter has become so stratified is a subject to be afterwards considered. The coal seams vary from a mere film, or a layer of less than a quarter of an inch in thickness, to 3 or 4 feet. It is not often, however, that the deposits are of the latter dimensions. In mines where the depth of the carbonaceous deposit averages from 10 to 20 or 30 feet, seams of mineral matters interpose themselves at intervals, varying as to the distance between them, but rarely exceeding the limits above assigned. All coal beds contain these foreign strata, or *partings*, to a greater or less extent; they seem to have been the result of the precipitation of matters held mechanically suspended in water. The thickness of these intervening deposits is found to vary considerably, from a mere seam to a bed of several feet. In many cases the mineral matter, thus interstratified, has become so saturated with bodies emanating from the coal, or during its formation blending with the carbon, that it ignites and burns like coal, only that its bulk of earthy substances remains, often retaining its original form. Such matters are often observed in the burning of many varieties of coal, and in common language are called *slates*, *batts*, or *basses*. This blending of the two substances is often so unmistakable that at a glance it may be ascertained whether the *shale*, as it is called, is argillaceous or calcareous; but when it is known that the coal beds belong to the alluvial deposits, it will be evident that the intermixture of mineral and organic matters must have proceeded collaterally, even although the latter appears in such excess as completely to obliterate any traces of the former. In Great Britain coal is principally in the carboniferous formations, occupying a posterior place in the series of stratified rocks; and where the same stratification of limestone rocks is met with in other countries, beds of coal are generally to be encountered. Still coal is not confined to this set of rocks; it is found in different parts of the strata, from the Devonian down to the most recent tertiary formations.

Mineralogical Characters.—Although here the subject under consideration is spoken of as a mineral, it ought to be remembered that, strictly speaking, it is not a pure one, but a mixture of various matters, of which carbon is the principal. It may, however, be regarded as organic matter *mineralized;* and as it manifests some of the general properties of minerals, these will be noticed. The several known varieties of coal possess each some distinctive feature, differing from one another in hardness, fracture, &c. Several species break up into cubical and rhomboidal fragments, whilst others, such as the anthracite, are nearly devoid of crystalline structure. Generally the fracture is conchoidal, uneven, fibrous, or slaty; in Boghead coal the fracture is conchoidal, perpendicular to the plane of stratification, but slaty when parallel. In colour it presents, according to the variety, every difference of hue, from jet-black to brownish-yellow; many kinds have a glossy brilliancy; others, such as the varieties of anthracites, a beautiful semi-metallic iridescent lustre; whilst some, such as the Wemyss, Methil, and other varieties of cannels, have a dull appearance. Coal exhibits great differences in point of hardness, although none of the varieties possesses it in an eminent degree. The gravity of several kinds of coal differs according to the texture and age; the lightest kinds have a density bordering on 1·00, whilst the heaviest range from 1·75 to 2·00.

Chemical Characteristics.—From what has been stated, it is evident that a chemical examination of coal would, in the simplest manner, lead to its division into inorganic substances, and that these are contained in it in variable proportions; and, further, that each of these classes can be resolved into other substances, the most characteristic of coal being those generated by the vegetable portion. This arises from the large proportion of the elements always found in it—namely, carbon, hydrogen, and oxygen; and which, by the action of heat out of contact with air, are converted into numerous and peculiar substances.

Distillation in close vessels resolves coal into solids, liquids, and gaseous bodies, consisting of carbon or coke, tar, ammoniacal liquor, benzol, naphtha, naphthalin, paraffin, paraffin oil, and illuminating and other gases, in various quantities. By the detection of these, and the proportion in which some are contained in the substance, a good inference may be drawn as to whether the body be coal or otherwise; nevertheless, the evidence is not so conclusive as when the investigation is conducted microscopically.

Microscopic Characters.—By the use of the microscope, the most conclusive proof of the origin of the coal is attained. Dr. AITKEN of Glasgow has carefully investigated the structure of coal, and found that, even in the most altered specimens, traces remain sufficiently characteristic to prove that the material is of vegetable origin.

In the variety of bitumens, whether pure mineral tar or asphaltum, no such structure is observable, and consequently, in the hands of a chemico-microscopist there is nothing to render the detection of real coal a matter of uncertainty.

Origin of Coal.—Such being the principal or more marked characters by which a substance submitted to examination may be affirmed to be *coal*, it will now be desirable to enter more fully upon the origin and nature of this product, in reference to its value as a fuel. Allusion has already been made to the analogy which exists between peat and coal, and the reader will have inferred that coal, like peat, has been produced by the decomposition of species of organic growth. All who have given attention to the composition of coal, and the geological position it occupies, concur in this view of the subject; and the different opinions will now be briefly explained which have been advanced as to the manner in which the change and disintegration of the vegetable products have been produced.

It may be said that the process which has operated to convert countless reproductions of plants into peat bogs, has been similar in the case of coals to some extent; but geologically considered, it is evident that the oldest peat deposits are of modern formation, when compared to the most recent beds of coal. Of the vegetable origin of the latter no doubt can be entertained, even if the microscope had not revealed the fact in the more compact varieties, since among other indications, even the trees have been found in their natural position converted into coal. The character, the variety, and the immense mass of vegetable matter thus converted, have led to the conclusion that the several species of plants whence coal has resulted were indigenous to a southern or equatorial climate, as it is certain they could not flourish so luxuriantly in the existing temperature of northern latitudes. The varieties most commonly distinguished in the different strata are ferns, calamites, sigillariæ, stigmariæ, and others; in fact, no less than 300 distinct kinds have been detected.

As to the manner, however, in which the strata of the coal deposits have been formed, there is much difference of opinion. Some geologists suppose that they were originally peat, the several successive layers being occasioned by successive subsidences of the land; whilst others assert that the various constituents were originally conveyed by currents to estuaries and deltas, where, being buried under the sand, mud, and debris brought down by the current, they were subsequently submitted to agencies which effected their carbonization. It is certain that the surface of the globe was at one time nearly submerged in an ocean, in which state it remained till, by the effects of volcanic eruptions, portions were uplifted, causing a corresponding depression in other places, and thus forming valleys, the forests and vegetation of which were buried under layers of loose earth and mud. At the same time, it would require many such forests to constitute a layer of the thickness of some of the coal seams, and these can scarcely be imagined to have been produced otherwise than by the drifting of vast accumulations of trees and plants into the basins in which coal is now found.

But leaving geologists to discuss and settle these questions, it is more in accordance with the plan of this work to attend to the chemical changes which have contributed to the conversion of the organic fibre into the carbonaceous matter in question. Whether the organic products on the surface of the earth were collected by changes in the relative position of the earth's solid crust, or by the force of violent currents, such as the large American rivers of the present day, it may be admitted and assumed as a fact that they were embedded with other matters saturated with moisture. The first natural change under such circumstances would be a fermentation of the albuminous matter and the gum, by which their molecular constitution would be broken up, and bodies of a simpler composition formed. The exclusion of the air after a short time would suppress the eremacausis or decay of the substance of the wood and fibrous matter, but the equilibrium of the affinities of the elements in the plants being broken, and considerable pressure being exerted, coupled with a certain rise of temperature, the change of elements arising from the new elective affinities would contribute to remove the hydrogen and oxygen to that extent which is observed in the composition of coal. The oxygen and hydrogen being most subject to the effect of this metamorphosis, these elements, leaving the carbon, would more readily assume their simplest and most permanent state of combination; but, as in the process of destructive distillation already alluded to, the conditions supplied are capable of inducing the water thus constituted to react upon a portion of the carbon, so in the coal formations, where the enormous pressure must have operated with an effect in some degree equivalent to an increased temperature, the moisture and excess of hydrogen would convert the remaining substance into carbonic acid and hydrocarbons respectively. The actual facts, as determined in coal mines, seem to bear out this view.

From such considerations it will be readily concluded that the elementary composition of coals must be different from ligneous fibre; but following up the assumed alteration by a symbolical representation, the composition of coal offers very conclusive grounds to warrant the opinion that the former has resulted from the latter in the manner indicated.

According to the degree of force exerted upon the decomposing substance, and the period of time in which this change was taking place, it is evident that the substances would be more or less removed from one another in composition. Thus the formula for splint coal may be deduced from that for ligneous fibre by supposing that heat and pressure combined have removed nine equivalents of carbonic acid, three equivalents each of water and marsh gas. In other kinds, such as many of the anthracites, the alteration is much greater than even in the splint already referred to, and it is much more difficult to recognize the analogy between them and wood, for often all the oxygen and hydrogen are removed, so that nothing is left but carbon and the mineral matters intermixed with it.

Coal Measures.—The region of the coal formations is very extensive, and includes many strata, all of which are known as the *coal measures*, or carboniferous group. Properly speaking the first of these is what is termed the *under-lay;* this is a tough argillaceous substance, which, upon drying, turns grey and becomes friable. It retains considerable traces of carbonaceous matters. Two other strata beneath this are, however, included in the group; these are the mountain limestone, which varies very much in thickness, being sometimes 900 feet, and the old red sandstone upon which it rests; the latter stratum ranges from 200 to 2000 feet in thickness. Next to the underlay in the ascending scale comes the seam of coal, or modified organic matter, varying from less than a quarter of an inch to several feet. Above these the upper layer or roof, as it is termed, rests. It is composed of slaty clay abounding in vegetable remains, as well as with crustaceæ, and several other matters. Interstratified with the latter are found various other substances, which seem to have been accumulations drifted by currents, such as laminated clay, grit, limestone, granite, sandstone, and other rocks.

All these deposits at one time, doubtless, formed regular horizontal layers, but through the effects of expansion or contraction of the earth they have been distorted and thrown into undulated positions, and where the internal force has been very great, they have, by the upheaval of the subordinate strata, been formed into large valleys or basins. From the position of these layers, previous to such convulsions occurring, it is obvious that as the older deposits of mountain limestone, old red sandstone, &c., emerged in succession, so the more modern layers, including the carboniferous, would appear at the surface. This appearance is termed the cropping out of the strata, and serves to indicate the side of the basin. Considerable irregularity is occasioned by further subterranean disturbances which tend to alter the position of the strata subsequently to the first upheaval of the older formations. These generally render the deposits somewhat irregular in shape, so that they seldom form a true basin. In some localities, as in the Leicester and Warwickshire coal-field, none of the characters of a basin are observed; in the latter instance, the seams are surrounded on all sides by overlying deposits, under which they dip or incline to a considerable depth, and extend to an area unknown.

Fig. 22 represents this field in section, showing the alluvial deposits at A A; the new red sandstone, or marls, at B B; the carboniferous shale and coal at CC, interlaid with carboniferous grit, or sandstones, D D; E, beds of magnesian; and F the stratum of mountain limestone, resting on the old red sandstone, G. Fig. 23 gives a faint idea of the disturbances which are occasioned in the various beds by fissures filled with other materials. These veins are, in the language of the miner, called *dykes*, as they are the means of separating the strata into compartments, which are designated *fields*. Besides this term, another is applied significant of the displacement of the bands of coal from their original position—namely, *shifts*. Where these occur the

Fig. 22.

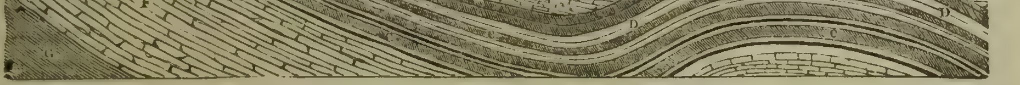
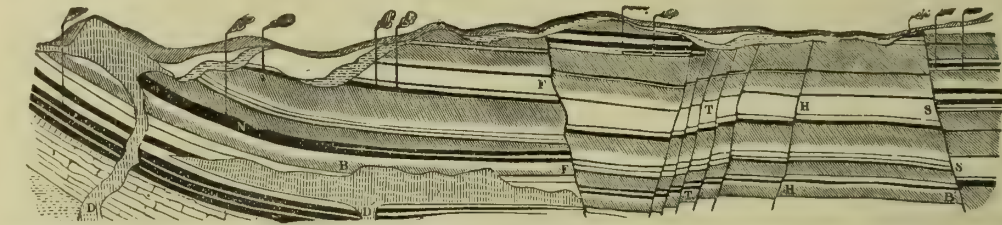


Fig. 23.



seam is thrown out of its level, and according as it is removed to a higher or lower one, the fault is called an *up-throw* or a *down-throw*. The displacement occurring at many of these shifts is considerable, and gives no small trouble to the miners. The largest known is that which runs through the Northumberland and Durham coal-field, and is termed the Ninety-fathom dyke, from the fact that the seams of coal are 90 fathoms lower at one side of the slip than at the other. Various matters fill these intersecting veins; hard and soft sandstone is contained in the one in question, which in some parts, especially at the Montague Colliery, attains a width of 22 yards. Two other dykes spring from this at the southern side; one of which takes a south-eastern direction, and is about 20 yards in breadth; the other a south-western one, and attains a breadth of 70 yards. Both branches are filled with the same material as the primary one, but do not appear to have caused so great a disturbance at their point of intersection. These are represented in the foregoing drawing at F F, S S; but the others, although they partake of the nature of a dyke, are not recognized as such. For instance, those shown at D D′ are of a different character, and are called *whin*-dykes, containing products of igneous origin, such as basalt, toadstone, &c.; these do not always cause a removal of the strata from the ordinary level. Evidence of their eruption in a state of fusion exists in the fact, that the coal in their vicinity is more or less charred and converted into a true coke; besides, many substances of a fusible nature are acted upon, and indicate the powerful temperature which has pervaded the place, and which is often productive of great loss by consuming or changing the coal into anthracite, as shown at D′ in the figure, where the basalt and other products accumulate. The *hitch* is another of those dykes, and is so called when its thickness is less than that of the seams of coal which it intersects: it is represented at H H in the drawing. Smaller veins of foreign matters lying in any direction contrary to that of the strata are designated *faults* or *troubles*, from the annoyance the miners experience by the interruption of their work. Several of these are seen at T T; and although in working they cause much trouble, yet sometimes they contribute to render a field more valuable, since, by the depression which they occasion, seams of coal are brought in which might otherwise be lost. An example of this is given in the drawing referred to, where, by the down-throw of the strata between F F and T T, two seams of coal are brought in which would not otherwise be contained in it. Other interruptions or irregularities in the coal seams are designated *bands* and *nips;* the former, shown at B, are thin deposits or beds of grit or shale occurring in the middle of a seam of coal, and which, from being very thin, gradually acquire greater thickness, till ultimately they reduce the seam so much as to render it valueless; the second, shown at N, is a sudden local thinning of the seam, from an excrescence of the roof or floor.

With regard to the production and consumption of coal, a very complete and careful paper appeared in the *Revue Universelle des Mines*, in the beginning of 1875, by VICTOR BOUHY, of which the following is a portion of an abstract appearing in the "Proceedings of the Institution of Civil Engineers," vol. xliii., p. 393:—

"The author ranges the countries which at the present time are the largest producers of coal in the following order:—1, England; 2, the United States; 3, the Zollverein; 4, Belgium and France; 5, Austria, including Hungary, and shows in a table the annual production in the first four of these groups. The fifth group gave in 1872 about one-fifth of that furnished by the fourth group.

"The development of this branch of mining industry has not proceeded equally in each of these countries. England has always furnished more than half the production of the whole world. Previous to the year 1830 her share amounted to $\frac{3}{4}$ of the total production; in 1845, to a little more than $\frac{2}{3}$; in 1858, it was still above $\frac{1}{2}$; in 1865 and 1868, the same proportion of about $\frac{3}{5}$ was maintained; and in 1872 it still exceeded the half by more than 7,000,000 tons. From 20,000,000 tons in 1830, the product had risen in England to 131,639,993 tons in 1872; that is, in forty-two years it had successively increased by more than 558 per cent. No accurate statistics of the production of the United States in 1830 are obtainable; but judging from those relating to the year 1845, it may be admitted that at the former date they occupied the fifth rank after England, Belgium, France, and Prussia. In 1872 they are in the second rank, with the important figure of 42,800,000 tons; that is, for the period of forty-two years, an increase of 2950 per cent. The Zollverein produced in 1830 less than Belgium and France—about 1,200,000 tons, exclusive of lignite. In 1872 this group figures for 33,400,000 tons of coal; that is, an increase of 2680 per cent. in forty-two years. Moreover, in addition to this quantity of coal, there were raised in 1872 about 9,018,000 tons of lignite.

The production of Belgium, which in 1830 amounted to 1,913,677 tons, had reached in 1872 a value of 15,658,948 tons; or an increase of 718 per cent. in forty-two years. At the former date Belgium occupied the second rank; at the latter date it had fallen to the fourth. The production of France has risen from 1,596,570 tons in 1830, to 15,204,170 in 1872; thus showing an increase in the forty-two years of 852·9 per cent. This country occupied at the former date the third place after England and Belgium; but at the latter date it was nearly on an equal rank with Belgium, in the fourth place after England, the United States, and the Zollverein. Austria produced in 1830 210,000 tons of coal and lignite; in 1860 the product of coal alone amounted to 1,948,189 tons, and in 1872 to 4,764,786 tons. It will be observed that the produce of France is constantly tending to equal that of Belgium; and it seems probable that the latter country will soon be left behind by its neighbour. This result is also indicated by the fact of the increase during the interval of forty-two years, between 1830 and 1872, being 718 per cent. in the case of Belgium, and 852·9 per cent. in the case of France. This notable increase of the production in France is due mainly to the great development of the mining industry in the departments of the north, and especially in the Pas-de-Calais. The author shows that these departments furnished 29 per cent. of the total production of France in 1834, and 39·04 per cent. in 1872. In the former year the quantity raised was only 4103 tons; in 1873 it had increased to 2,978,647 tons. This coal-field would seem to be yet hardly touched; and the intelligence and skill which have been shown in laying out and opening up the workings in this locality, together with the readiness with which capital has been placed at the disposal of the engineer, are evidences that the future of this northern field will be marked by yet greater success.

"The author concludes this portion of his report with statistics relative to the total coal production of the world in 1872:—In Europe, England furnished 131,640,000 tons; in America, the United States furnished 42,794,000 tons, a large portion of which was anthracite; and Nova Scotia, Chili, and British Columbia, 810,000 tons. In Australia, New South Wales furnished 1,300,000 tons; and Queensland and New Zealand, 47,000 tons. And in Asia, India furnished 650,000 tons; and Japan, China, and Burmah, 44,000 tons. The total quantities amount to 248,144,200 tons, of which England furnished more than half.

"The second part of the report is devoted to the consumption of coal, and in a table it is shown that it has increased during the ten years ending 1872, in the Zollverein by 116 per cent., in France by 35·6 per cent., in England by 47 per cent., and in Belgium by 45·5 per cent.; and the increase in these countries during the thirty years preceding the above-mentioned date was 1460 per cent., 324 per cent., 249 per cent., and 227 per cent. respectively. The increase in the Zollverein is very great relatively to the other countries, and in France it is especially remarkable. In both cases the increase is mainly due to the development of metallurgical industry and the extension of railways. As a consumer of coal, France takes the fourth place after England, America, and the Zollverein; but England, it will be observed, has an enormous lead. It appears from the statistics which have been prepared that there are at present but three countries in the world that raise more coal than they consume—namely, England, Belgium, and the Zollverein, which consequently export that mineral in considerable quantities."

Different Kinds of Coal.—From the acknowledged transformation which the substance of the coal has undergone, and from its progressive nature, it is natural to expect that the material so produced should have very different properties, according to its more or less advanced state of decomposition. Such is really the case, and various species of coal exist differing by slight and regular gradations from the most recent lignite or brown coal, in which the outline of the wood may be most easily traced, up to the most perfect anthracite, in which every vestige of the original is lost, and nothing remains but a conglomerated charcoal. Many of them, indeed, have so close a resemblance to one another, and pass so imperceptibly from one stage to the other, that it is almost impossible to mark the distinction between them. Several species, however, may be classified on broader data, grounded partly upon age, partly on their physical appearance, and partly on their composition. It is by these criteria that the classification of the fossil into brown or black coal, or into the bituminous or non-bituminous varieties, is effected. Several members are contained in each of these groups, but many kinds blend with each other in such a manner that it is difficult to draw a line of demarcation between them. Classifying the chief varieties according to their supposed age, the whole of the coal measures may be included under three heads, namely, the younger coal of the *tertiary* deposits, the older bituminous kind of the secondary formations, and the anthracites of the older transition series of rocks.

Lignite.—The coal of the tertiary formation, which includes several varieties, has been designated *brown coal* or *lignite*, from its characteristic appearance. This species, termed also bituminous wood, is the most interesting, as clearly exhibiting the ligneous structure of the matter from which it derives its name, in such perfection as to furnish sufficient data for instituting a diagnosis of the plants of very remote eras. It has a brown colour, but this varies with the depth of the bed. The Bovey coal of Devonshire is a member of this class; it presents a distinct woody structure, and very rarely a conchoidal fracture; it is devoid of lustre, is brittle, and burns readily, leaving a white ash. Some others, however, such as the more compact kinds, exhibit a more or less conchoidal fracture and slightly resinous lustre. In the latter case the colour is brownish-black; it has been called earthy-brown, to distinguish it from another kind of the same species, designated *pitch-coal*, the structure of which is more dense, as shown by its distinct conchoidal appearance when broken. Between these extremes may be found the *brown earthy coal*, so named from its argillaceous fracture, crumbling into loose friable particles, and *moor coal*, in which the structure of the plants is obliterated, and which exhibits in its fracture more or less lustre.

The species of coal embracing these varieties is encountered in several of the formations on the Continent, at Bovey Tracey in Devonshire, near Lancaster, and at Lough Neagh in Ireland, where it constitutes three beds, averaging in some parts a thickness of 60 feet. It is very inferior as a fuel to the other varieties of coal which will be presently described. As dug from the mine it is more or less impregnated with moisture, which it persistently retains, and which, even if entirely expelled, is reabsorbed with great avidity. Thus Reinsch determined in a sample of wood coal from the Upper Pfalz, in Bavaria, 43 per cent. of moisture, and in an earthy-brown coal, 30. Varrentrapp found no less than 48 per cent. of moisture in fresh lignite from Helmstadt, and further ascertained that, after thorough desiccation and re-exposure to air, about 8 per cent. of water was again absorbed. By stacking this coal for some time much of the water evaporates, so that the moisture averages about 30 per cent.; but if the exposure be made in summer the quantity is lessened to 20 per cent., the bulk of the coal undergoing a corresponding reduction.

Distinct from the foregoing in physical appearance, though to some degree analogous in chemical composition, are those non-compact bodies, termed bituminous coal, in which the structure of the plants is entirely effaced, and the colour and appearance are indicative of a pretty advanced stage of decomposition. Of this kind there are several varieties, distinguished by characteristic properties. When treated with ether they all yield more or less bitumen, and hence the general designation, *bituminous*, to distinguish them from the anthracites proper, which afford none of that substance. The following most marked varieties of this description are *caking coal*, *splint coal*, *cherry coal*, and *cannel* or *parrot coal*.

Caking coal is a moderately compact fuel; its fracture is uneven, and its lustre varies from a resinous to a velvety or grayish-black appearance. When heated it breaks into small pieces if the amount of bitumen be not more than the average, but afterwards the fragments agglomerate and form a hard compact body; when the percentage of bitumen is high it forms at once into a pasty mass, and during the application of the heat bubbles of gaseous matter escape, leaving ultimately a carbonaceous substance, in which all traces of the original are effaced. Ignited in air it burns with a yellowish flame, which is intermittent, unless the fuel be kept repeatedly stirred, so as to prevent its caking. The latter tendency renders this coal unsuitable for many operations where great heat is required, as the draught is impeded by its caking properties. It is, however, a valuable fuel, especially as it is very often possessed of qualities which render it applicable for the manufacture of gas and coke, the latter being most eligible as a heating agent where the coal itself cannot be employed.

Caking coal is very general, being met with in almost all the coal-fields of Great Britain, but more especially in the Newcastle and Wigan districts.

Splint or Hard Coal.—This variety occurs most abundantly in the Glasgow coal deposits, where, for general application, it is highly prized. Its colour is black or brownish-black, and its lustre resinous and glistening. When broken, the principal fracture appears imperfect and slaty, but the transverse one shows it to be fine-grained, uneven, and splintery; hence, as well as from its hardness, the term splint. It kindles with greater difficulty than the preceding variety, but when once ignition has taken place, it produces a fine clear fire, and throws out much heat.

Cherry or Soft Coal.—The similarity in physical appearance between this and the caking coal is very great, though for the most part the lustre of cherry coal is much more splendent, and hence the name given it by the miners. It differs from caking coal in not undergoing fusion when heated. Owing to its great brittleness, it is not economical in the working. It readily ignites, and makes a lively fire, yielding a clear yellow flame, but is consumed rapidly. This species is likewise met with in the upper strata of the Glasgow beds, as also in Staffordshire, and in the Lancashire district.

Cannel, Candle, or Parrot Coal.—This variety has a very compact and even texture, a shining resinous lustre, and a colour varying between jet and a greyish or brownish black. The lustre of cannel coal is sometimes not so very distinct as that of *pitch coal*, which is a species of the caking kind; its compact texture and gravity are sufficiently characteristic to distinguish it from the other sorts. The fracture of cannel is flat, conchoidal in every direction, and sometimes slaty. It takes a good polish, and on this account is manufactured into numerous articles, such as inkstands, snuff-boxes, beads, &c.

Cannel is found in several coal basins, but most abundantly in the Wigan district, at Lesmahagow, near Glasgow, and at Coventry. It is so named from its property of burning and yielding a bright flame like a candle. The other name, *parrot coal*, which is of Scottish origin, is derived from its decrepitation when thrown on the fire, owing to pieces of the coal flying off when heated.

Many other local appellations are given to the coal even from the same field, if it includes many seams, but these are of little interest to the consumer.

Anthracite.—In speaking of the origin of coal, allusion has been made to this variety as being the oldest, and, consequently, the furthest removed from its vegetable source in composition and physical characters. This fossil, which is sometimes known as *glance* or *stone* coal, is a hard compact substance possessing much lustre, often iridescent; the more perfect variety is entirely free from bituminous matter, and hence it constitutes a class of the coal formation in itself. These characters are not observed in all the anthracites, which generally retain more or less bituminous coal interstratified or otherwise mixed with portions reduced to the state of true anthracite. The mixed varieties, or semi-anthracites, admit of being employed as a substitute for caking coals in many cases where a true anthracite would not answer the purpose.

This is the densest of all the coals known, excepting such as are very earthy or otherwise mineralized. It contains, when a true anthracite, only carbon, water, and inorganic salts, but generally more or less hydrogen and oxygen, besides the proportion of the latter elements in the form of water. Anthracite is ignited with great difficulty, and being dense, and having a tendency to break up into fragments when heated, in consequence of the expulsion of the water contained in it, it is not calculated to produce a strong fire in the ordinary grate or furnace, although, when once thoroughly ignited, its heating power is very great. By a suitable modification of the grate or furnace, and proper management, it may in numerous instances—not the least of which is its application to smelting — be employed with advantage.

Anthracite is found most extensively in America, where it constitutes immense deposits. In England it is chiefly worked in the South Wales coal-field, although it may be met with in large quantities in other basins.

CHEMICAL COMPOSITION OF COAL.—The localities and general characteristics of the principal varieties of coal having been noticed, a more minute examination of its composition will now be made. It has been already laid down as a general principle, that the value of a fuel is proportional to the amount of carbon which it contains. Like other rules, however, this admits of exceptions, and for some purposes the coal is valued according to its percentage of hydrogen. This is especially the case with coal intended for gas manufacture, and also when employed as a fuel in such arts as require the heat to exert its power at some distance from the fire. Moreover, other ingredients may be contained in the coal in proportions very insignificant when compared with the carbon and other inflammable portion; thus nitrogen is nearly always present in coal in small proportions, and it has evidently come from the original wood, which always contains nitrogen in some form, and hence its presence in the coal. There is always found in coal inorganic matter, derived both from the original plants and from water holding such matter in solution; such are silica, lime, oxide of iron, and alumina; and these substances form the ashes of the burnt coal, and both by the amount and composition of its ash the value of a coal is considerably modified. Other ingredients are so injurious in their effects as to render the fuel unadapted for many purposes to which it might otherwise be applied with good results. Among these are found sulphur, arsenical and other kinds of pyrites; and similar prejudicial effects are produced by the presence of considerable portions of sulphates, or, in fact, of any mineral matters which undergo no change during the combustion. The pyritous ingredients are, however, the most deleterious, as during combustion they evolve sulphurous acid, and if arsenic be contained in the coal—which is fortunately a rare occurrence—arsenious acid will be eliminated. Now, both the sulphurous and arsenious acids are highly obnoxious and dangerous, and ought to be avoided as much as possible. When iron pyrites are found in coal there is always found in the ash an equivalent amount of ferric oxide; and when this is present in large amount it has the effect of fusing the coal and producing clinkers. Besides these are found galena and micaceous iron ore in the coals of the carboniferous series. From all these considerations, it is evident that, to determine the quality of any species of coal with a view to ascertain its fitness for a given purpose, nothing short of a knowledge of its ultimate composition can be relied on; and this can only be arrived at by careful analyses. Before proceeding further, therefore, the difference in chemical composition of the principal varieties will be examined.

Lignites.—It has been stated that this species of coal belongs to the tertiary or latest formations, and retains much of the ligneous structure from which it derives its name. The general results of its distillation are a coke or charcoal containing mineral matters—aqueous products, more or less charged with pyroligneous acid and ammonia, tar, the hydrocarbons, carbonic oxide, and carbonic acid. The relative proportions of these vary in different specimens; but, on the whole, they exhibit a great similarity of composition in this substance, as compared with peat and wood—more especially the former. By further treatment the analogy is more fully established: thus, when lignite is treated with caustic potash it dissolves, yielding a dark-brown liquor, which affords a substance resembling in its reactions ulmin, the principal ingredient of peat. Again, the coke which remains after the distillation of lignite retains the outline of the sample operated upon, just as in the case of peat or wood, a circumstance which happens with no other kind of coal. It is to be observed, however, that these characteristics apply only to strongly-marked lignite or brown coal. The transition from this to true coal is gradual, both as regards the physical and chemical properties. The composition of lignite varies according to the age and position of the deposit, but this difference is chiefly confined to the mineral and aqueous constituents, which vary from less than 1 to nearly 60 per cent. For example, the amount of ash in a species of pitch coal from Herschberg is only 0·81 per cent., while in a variety from the banks of the Rhine it is 58 per cent. But those which contain the larger amount can scarcely be classed with fuels, as they cannot be economically used in that capacity, except, perhaps, for the combustion of shaly matters, as in the manufacture of alum. A much closer coincidence is found between the elementary composition of the organic matter in different specimens than appears in the mineral portion, as is shown by the annexed tabulated results of the analysis of several varieties:—

ELEMENTARY ANALYSES OF BROWN COAL.

Brown Coal or Lignite.	Centesimally. Carbon.	Centesimally. Hydrogen.	Centesimally. Oxygen and Nitrogen.	Observer.
Earthy, from Dax,	69·52	5·59	19·90	Regnault.
“ Bouches du Rhône,	63·01	4·58	18·98	
“ Neider-Alpen,	69·05	5·20	22·74	
Earthy—consisting of stems—from Meissner,	70·12	3·19	7·59	Kühnert.
“ pitch coal,	56·60	4·75	27·15	
“ “ from Ringkuhl, Hirschberg,	60·83	4·36	24·64	
“ “ “ Habichtswald,	57·26	4·52	26·10	
“ lustrous coal, Ringkuhl,	66·11	4·82	18·51	
“ allied to pitch coal, Habichtswald,	54·18	4·20	26 98	
“ lowest vein at Ringkuhl,	52·98	4·09	21·91	
“ middle,	54·96	4·01	22·31	
“ Stillberger,	50·78	4·62	21·38	
“ Helmstadt, Prince of Wales mine,	68·57	4·84	19·87	Varrentrapp.
“ “ another mine,	67·88	6·85	17·46	
“ Schönengen Treue mine,	63·71	5·07	22 79	
“ “ another pit,	64·80	4·54	23·12	
Lignites from Ringkuhl,	51·70	5·25	30·37	Kühnert
“ Greece,	60·36	5·00	25·62	Regnault.
“ Cologne,	63·42	4·98	27·11	
“ Usnach,	55·27	5·70	36·84	
“ Laubach,	57·28	6·03	36·10	Liebig.
Earthy brown coal from Wigan,	80·21	6·30	8·54	J. A. Phillips.
“ “ Conception Bay,	70·33	5·84	16·34	Admiralty Coal Investigation.
Lignite from Sandy Bay, Patagonia,	62·19	5·08	19·44	
“ Talcahmano Bay,	70·71	6·44	16·93	
“ Lough Neagh, Ireland,	58·56	5·95	26·85	Kane.
“ “ “ another sample,	51·36	7·35	25·08	

The average content of nitrogen ranges from 0·5 to 1·5 per cent. Taking the mean of the numbers representing the components of the true lignites, the results would indicate the annexed composition:—

	Centesimally.
Carbon,	63
Hydrogen,	5
Oxygen and nitrogen,	32
	100

But if the whole of the oxygen be assumed to be united with the hydrogen so as to form water, the actual constitution of the substance would be represented by 63 parts of carbon, 1 of hydrogen, and 36 of water. Some varieties of this species of coal are used in the manufacture of various articles of ornament, especially in France, where the business is carried on with considerable success.

Bituminous Coals.—Bituminous coal bears a general resemblance to the last, inasmuch as both contain the same substances, varying in relative quantity. Analysis, however, cannot always determine between them, and the physical marks noted in the preceding pages must be observed narrowly before deciding. For the most part, the density of bituminous coal is greater than that of the lignite or brown coal, unless the latter be very earthy and compact. REGNAULT gives the density of the varieties of lignite which he examined, when in the dry state, as between the extremes of 1·100 and 1·85. Earthy coal he found to have a specific gravity of 1·254 to 1·276; but other varieties afforded KUHNERT a density of 1·310 to 1·436. Many of these numbers are much higher than that of the densest bituminous coal; but this must be attributed to the superabundant presence of mineral matters. At the same time, the gravity of a true homogeneous coal is not always to be inferred from the amount of ash which it yields, although some investigators have endeavoured to establish a constant relation between the density of the coal and its inorganic constituents. It is evident, indeed, that a substance may be very dense in its nature, and yet, from its state of aggregation, may give but a medium indication when its gravity is determined in bulk. This has been observed in the case of wood and charcoal, and equally applies to the substance under examination.

From the tables it may be seen that the specific gravity of coal ranges from 1·2 to 1·5, rarely exceeding the latter; and further, by rejecting those samples which yield very large percentages of ash, the mean gravity will be about 1·30. It will also be observed, that the relation existing between the mineral constituents of the coal and the density is quite irregular, and consequently offers no trustworthy grounds for inferring the percentage of ash which a coal may contain merely by determining the density, or inversely. It is true, however, that in numerous instances samples with a larger proportion of ash will be found to have a higher density than those which contain less inorganic matter.

This is more especially the case with different samples of coal from the same mine, which led JOHNSON to infer that the specific gravity and mineral constituents of the coal from the same bed have a constant relation to one another. The basis on which he erected this theory in found in the following results of the analyses of four samples of coal from Beaver Creek, Lucerne County:—

	Specific Gravity.	Percentage of Ash.
No. 1,	1·560	1·28
“ 2,	1·594	4·00
“ 3,	1·613	5·01
“ 4,	1 630	5·063

The same increase was observed with four other samples from the coal field of Maryland, bordering on Pennsylvania, thus:—

Mean Specific Gravity of two Specimens.	Mean Percentage of Earthy Matters in two Specimens.
1·320	7·52
1·350	9·58
1·365	10·35
1·385	11·75
1·485	14·41

Admitting that a high density is to some extent an indication of the presence of mineral matters in greater abundance, yet is impossible, even approximately, to estimate the percentage of these by this test, since no fixed and constant relation can be established between the two. Besides, it is well known that a great difference in the amount of mineral matters is sometimes detected in coal from the same working.

The nature of the inorganic matters in coal affects, in a great degree, not only the gravity of the substance, but its quality as a fuel, although the components found are generally the same in all. The following table of the analyses of the ashes of coal by PHILLIPS, shows the nature and extent of the components, which, strange to say, contain no alkalies:—

	NAME.	Silica.	Alumina and oxide of iron.	Lime.	Magnesia.	Sulphuric acid	Phosphoric acid	Total per centage.	Per centage of ash in coals.	Per centage of coke in coals.
Welsh.	Pontypool,	40·00	44·78	12·00	trace.	2·22	0·75	99·75	5·52	64·8
	Bedwas,	26·87	56·95	5·10	1·19	7·23	0·74	98·08	6·94	71·7
	Porthmawr,	34·21	52·00	6·199	0·659	4·12	6·633	97·821	2·91	63·1
	Ebbw Vale,	53·00	35·01	3·94	2·20	4·89	0·88	99·92	14·72	77·5
	Coleshill,	59·27	29·09	6·02	1·35	3·84	0·40	99·97	10·70	—
Scotch.	Fordell,	37·60	52·00	3·73	1·10	4·14	0·88	99·45	1·50	52·03
	Splint,									
	Wallsend,	61·66	24·42	2·62	1·73	8·33	1·18	99·99	4·0	58·45
	Elgin,									

The same elements are contained in the ashes of brown coal, though in different proportions, as will be seen from the subjoined analysis by VARRENTRAPP:—

	Analyses of Ashes of Brown Coal from Brunswick, represented Centesimally.
Lime,	23·67
Magnesia,	2·58
Alumina,	11·57
Oxide of iron,	5·78
Carbonate of potassa,	2·64
Silica and clay,	19·27
Sulphuric acid,	33·83
Loss,	0·66
	100·00

Lead, copper, iron pyrites, and traces of iodine, &c., are also found in coal, but are by no means general. In fact, the traces of lead and copper are sometimes so minute as not to admit of estimation; but this is not the case with the iron pyrites. In some varieties this compound may be readily distinguished in clusters of cubic crystals, or in seams running through the mass; and from its characteristic yellow appearance, the coals in which it is thus found are named *brassy coals*. It operates more injuriously than any of the other mineral compounds, as during the combustion the sulphur is transformed into sulphurous acid, which in itself is poisonous; and although it passes off considerably diluted by the other gases produced, yet it is hurtful not only to animal life, but to many manufacturing processes, as well as to the boilers and furnaces of locomotives. When sulphurous coals are distilled, one-half or a certain portion of the sulphur is eliminated in the form of sulphide of hydrogen and sulphide of carbon, whilst the remainder is left united with the metallic base in the coke. In both cases it is the cause of much trouble and injury, as every gas manufacturer and smelter well knows. But these are not the only evils resulting from the iron pyrites. When coals containing it in large quantities are stored, and are affected with moisture, it not unfrequently happens that spontaneous ignition sets in, in consequence of the bisulphide being converted by its oxidation into sulphate of iron, and generating at the same time as much heat as determines the combustion of the carbonaceous matter, which ultimately may reach to a red heat. To guard against this danger, it is well to expose the heap as much as possible to a current of air, in order that the moisture may spontaneously pass off, and the entire mass be kept cool; or if incipient combustion has already set in, it may be arrested by loosening and turning over the heap, so that the air may pass through it freely. This spontaneous combustion is more apt to take place in mines than in the coals even when stored, unless, indeed, they are accumulated in confined places where the temperature is somewhat elevated. Under such circumstances, aided by the presence of moisture, the coals are very liable to burn voluntarily. Although the combustion which has been going on in some mines for considerable periods cannot be attributed to the oxidation of the pyrites, but rather to the large volumes of inflammable gases which are generated in crevices in the mass, and which are accidentally ignited, yet it cannot be doubted that, through the combined action of water and a limited supply of air, the mineral assists in developing the heat throughout. Flooding by water is the only effective precaution that can be adopted for extinguishing fire in coal mines, for the numerous fissures in the coal, which often extend to the surface, serve the purpose of powerful chimneys, whilst other chinks co-operate with the shafts in conveying air to the seat of the fire. Every exertion has been made to check the combustion going on in some of the British mines by the erection of dams; but although it is believed that in some of them the rate of consumption is much reduced, it still continues.

Although the specific gravity of coals and the percentage of ash which they contain are very insufficient tests of their value as fuel, yet it is evidently important to know the amount of the combustible constituents in different kinds. Fortunately, numerous analyses of coals have been made; and the editor feels assured that a summary and compendious view of the most important of these cannot fail to be deeply interesting to all who are concerned in those arts and manufactures in which fuel is an object of primary consideration, as well as to the scientific analyst. Accordingly, the following tables exhibit the results so elaborately worked out for the Admiralty by Dr. LYON PLAYFAIR and others, in their examination of nearly all the products of the British coal mines:—

MEAN COMPOSITION OF AVERAGE SAMPLES OF WELSH COALS.

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Aberaman Merthyr,	1·305	90·94	4·28	1·21	1·18	0·94	1·45	85·0
Ebbw Vale,	1·275	89·78	5·15	2·16	1·02	0·39	1·50	77·5
Thomas's Merthyr,	1·30	90·12	4·33	1·00	0·85	2·02	1·68	86·53
Duffryn,	1·326	88·26	4·66	1·45	1·77	0·60	3·26	84·3
Nixon's Merthyr,	1·31	90·27	4·12	0·63	1·20	2·53	1·25	79·11
Binea,	1·304	88·66	4·63	1·43	0·33	1·03	3·96	88·10
Bedwas,	1·32	80·61	6·01	1·44	3·50	1·50	6·94	71·7
Hill's Plymouth Work,	1·35	88·49	4·00	0·46	0·84	3·82	2·39	82·25
Aberdare Co.'s Merthyr,	1·31	88·28	4·24	1·66	0·91	1·65	3·26	85·83
Gadly Nine-feet Seam,	1·33	86·18	4·31	1·09	0·87	2·21	5·34	86·54
Resolven,	1·32	79·33	4·75	1·38	5·07	included in ash.	9·41	83·9
Mynydd Newydd,	1·31	84·71	5·76	1·56	1·21	3·52	3·24	74·8
Abercarn,	1·334	81·26	6·31	0·77	1·86	9·76	2·04	68·4
Anthracite, Jones and Co.,	1·375	91·44	3·46	0·21	0·79	2·58	1·52	92·9
Ward's Fiery Vein,	1·344	87·87	3·93	2·02	0·83	included in ash.	7·04	—
Neath Abbey,	1·31	89·04	5·05	1·07	1·60	—	3·55	61·42
Graigola,	1·30	84·87	3·84	0·41	0·45	7·19	3·24	85·5
Gadly Four-feet Seam,	1·32	88·56	4·79	0·88	1·21	—	4·88	88·23
Machen Rock Vein,	1·297	71·08	4·88	0·95	1·37	17·87	3·85	65·2
Birch Grove, Graigola,	1·360	84·25	4·15	0·73	0·86	5·58	4·43	85·1
Llynvi,	1·28	87·18	5·06	0·86	1·33	2·53	3·04	72·94
Cadoxton,	1·378	87·71	4·34	1·05	1·75	1·58	3·57	82·0
Oldcastle Fiery Vein,	1·280	87·68	4·80	1·31	0·09	3·39	2·61	79·8
Vivian and Sons' Merthyr,	1·290	82·75	5·31	1·04	0·95	4·64	5·31	67·1
Llangennech,	1·312	85·46	4·20	1·07	0·29	2·44	6·54	83·69
Three-quarter Rock Vein,	1·34	75·15	4·93	1·07	2·85	5·04	10·96	62·5
Pentrepoth,	1·31	88·72	4·50	0·18	—	3.24	3·36	82·5
Cwn Frood Rock Vein,	1·255	82·25	5·84	1·11	1·22	3·58	6·00	68·8
Cwm Nanty Gros,	1·28	78·36	5·59	1·86	3·01	5·58	5·60	65·6
Brymbo Main,	1·300	77·87	5·09	0·57	2·73	9·52	4·22	55·4
Tivian and Sons' Rock Vawr,	1·301	79·09	5·20	0·66	2·41	8·34	4·30	58·6
Coleshill,	1·29	73·84	5·14	1·47	2·34	8·29	8·92	56·0
Brymbo Two-yard,	1·283	78·13	5·53	0·54	1·88	8·02	5·90	56·2
Rock Vawr,	1·29	77·98	4·39	0·57	0·96	8·55	7·55	62·50
Porth-mawr,	1·39	74·70	4·79	1.28	0·91	3·60	14·72	63·1
Pontypool,	1·32	80·70	5·66	1·35	2·39	4·38	5·52	64·8
Pentrefelin,	1·358	85·52	3·72	trace	0·12	4·55	6·09	85·0

MEAN COMPOSITION OF AVERAGE SAMPLES OF NEWCASTLE COALS.

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Willington,	—	86·81	4·96	1·05	0·88	5·22	1·08	72·19
Andrew's House, Tanfield,	1·26	85·58	5·31	1·26	1·32	4·39	2·14	65·13
Bowden Close,	—	84·92	4·53	0·96	0·65	6·66	2·28	69·69
Haswell Wallsend,	1·2 6	83·47	6·68	1·42	0·06	8·17	0·20	62·70
Newcastle Hartley,	1·29	81·81	5·50	1·28	1·69	2·58	7·14	64·61
Hedley's Hartley,	1·31	80·26	5·28	1·16	1·78	2·40	9·12	72·31
Bates' West Hartley,	1·25	80·61	5·26	1·52	1·85	6·51	4·25	—
West Hartley Main,	1·204	81·85	5·29	1·69	1·13	7·53	2·51	59·20
Buddle's West Hartley,	1·23	80·75	5·04	1·46	1·04	7·86	3·85	—
Hastings' Hartley,	1·25	82·24	5·42	1·61	1·35	6·44	2·94	35·60
Carr's Hartley,	1·25	79·83	5·11	1·17	0·82	7·86	5·21	60·63
Davison's West Hartley,	1·25	83·26	5·31	1·72	1·38	2·50	5·84	59·49
North Perey Hartley,	1·25	80·03	5·08	0·98	0·78	9·91	3·22	57·18
Haswell Coal Co.'s Steamboat Wallsend,	1·27	83·71	5·30	1·06	1·21	2·79	5·93	61·38
Derwentwater Hartley,	1·26	78·01	4·74	1·84	1·37	10·31	3·73	54·83
Broomhill,	1·25	81·70	6·17	1·84	2·85	4·37	3·07	59·20
Original Hartley,	1·25	81·18	5.56	0·72	1·41	8·03	3·07	58·22
Cowpen & Sidney's Hartley,	1·26	82·20	5·10	1·6	0·71	7·97	2·33	58·59

MEAN COMPOSITION OF AVERAGE SAMPLES OF DERBYSHIRE COALS.

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Earl Fitzwilliam's Elsecar,	1·296	81·93	4·85	1·27	0·91	8·58	2·46	61·6
Holyland and Co.'s Elsecar,	1·317	80·05	4·93	1·24	1·06	8·99	3·73	62·5
Earl Fitzwilliam's Park Gate,	1·311	80·07	4·92	2·15	1·11	9·95	1·80	61·7
Butterly Co.'s Portland,	1·301	80·41	4·65	1·59	0·86	11·26	1·23	60·9
Butterly Co.'s Langley,	1·264	77·97	5·58	0·80	1·14	9·86	4·65	54·9
Stavely	1·27	79·85	4·84	1·23	0·72	10·96	2·40	57·86
Loscoe Soft,	1·285	77·49	4·86	1·64	1·30	12·41	2·30	52·8

MEAN COMPOSITION OF AVERAGE SAMPLES OF LANCASHIRE COALS.

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Inch Hall Co.'s Arley,	1·272	82·61	5·86	1·76	0·80	7·44	1·53	64·0
Haydock Little Delf,	1·257	79·71	5·16	0·54	0·52	10·65	3·42	58·1
Balcarres Arley,	1·26	83·54	5·24	0·98	1·05	5·87	3·32	62·89
Blackley Hurst,	1·26	82·01	5·55	1·68	1·43	5·28	4·05	57·84
Ince Hall, Pemberton Yard,	1·348	80·78	6·23	1·30	1·82	7·53	2·34	60·6
Haydock, Rushy Park,	1·323	77·65	5·53	0·50	1·73	10·91	3·68	59·4
Moss Hall, Pemberton, Four-feet,	1·258	75·53	4·82	2·05	3·04	7·98	6·58	55·7
Haydock Higher, Florida,	1·218	77·33	5·56	1·01	1·03	12·02	3·05	51·1
Ince Hall, Pemberton, Four-feet	1·276	77·01	3·93	1·40	1·05	5·52	1·09	57·1
Blackbrook Little Delf,	1·26	82·70	5·55	1·48	1·07	4·89	4·31	58·48
King	1·300	73·66	5·30	1·68	1·58	9·06	8·72	62·4
Rushy Park Mine,	1·28	77·76	5·23	1·32	1·01	8·99	5·69	56·66
Blackbrook, Rushy Park,	1·27	81·16	5·99	1·35	1·62	7·20	2·68	58·10
Johnson and Wirthington's, Rushy Park,	1·28	79·50	5·15	1·21	2·71	9·24	2·19	57·52
Laffak, Rushy Park,	1·35	80·47	5·72	1·27	1·39	8·33	2·82	56·26
Balcarres, Haigh Yard,	1·28	82·26	5·47	1·25	1·48	5·64	3·90	66·09
Haydock, Florida Main,	1·267	77·49	5·50	1·27	0·88	12·84	2·02	54·4
Wigan, Four-feet,	1·209	78·86	5·29	0·86	1·19	9·57	4·23	60·0
Ince Hall, Pemberton, Five-feet	1·269	68·72	4·76	2·20	1·35	18·63	14·34	56·5
Cannel—Wigan	1·23	79·23	6·08	1·18	1·43	7·24	4·84	60·33
Ince Hall Co.'s Furnace Vein,	1·314	74·74	5·71	1·53	0·96	13·52	4·04	58·4
Balcarres, Lindsay,	1·26	83·90	5·66	1·40	1·51	5·53	2·00	57·84
Caldwell and Thomson's, Rushy Park,	1·271	76·17	5·46	1·09	0·91	14·87	1·50	58·7
Barcarres, Five-feet,	1·26	74·21	5·03	0·77	2·09	8·69	9·21	55·90
Moss Hall, Pemberton, Five-feet,	1·283	76·16	5·35	1·29	1·05	10·13	6·02	56·1
Moss Hall Co.'s New Mine,	1·278	77·50	5·84	0·98	1·36	12·16	3·16	57·7
Caldwell and Thomson's Higher Delf,	1·274	75·40	4·83	1·41	2·43	19·98	5·95	54·2
Johnson and Wirthington's Sir John,	1·31	72·86	4·98	1·07	1·54	8·15	11·40	56·15

MEAN COMPOSITION OF VARIOUS SCOTCH CANNEL COALS, ANALYSED BY DR. PENNY OF GLASGOW.

Locality, or Name of Coal.	Specific gravity.	Volatile matters.	Fixed carbon.	Ash.	Sulphur.	Water.	Coke.
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1. Rochsoles—1851,	1·448	53·7	4·9	38·8	1·6	1·0	43·70
2. Hardie's—1852,	1·420	34·0	4·0	58·4	*	3·6	62·40
3. Boghead, *Brown*—1851,	1·160	71·06	7·10	21·2	0·24	0·4	28·30
4. Boghead, *Black*—1851,	1·2185	62·7	9·25	26·5	0·35	1·2	35·75
5. Torbanehill—1853,	1·1892	67·11	10·52	21·0	0·32	1·05	31·52
6. Boghead—1849,	1·1550	71·3	11·3	16·8	(·34)	0·6	28·10
7. Bathville,	1·201	64·35	12·6	22·2	0·25	0·60	34·80
8. Stand—Airdrie,	1·4647	52·08	14·77	32·0	*	1·15	46·77
9. Methill,	1·3002	49·23	17·57	29·7	*	3·50	47·27
10. Capeldrae,	1·3603	45·73	19·97	31·5	*	2·80	51·47
11. Wemyss,	1·1831	58·52	25·28	14·25	*	1·95	39·53
12. Balbardie,	1·420	38·96	29·66	28·0	0·38	3·0	57·66
13. Hillhead—Kilmarnock,	1·602 1·320	36·65	32·34	27·4	0·61	3·0	59·74
14. Brymbo,	*	32·10	36·4	29·4	*	2·1	65·80
15. Lesmahagow—Auchinheath,	1·1990	56·23	36·7	4·3	0·55	2·22	41·00
16. Bartonshill,	1·280	46·0	39·6	10·0	2·0	2·4	49·60
17. Bartonshill,	1·350	38·0	37·9	18·7	2·2	3·2	56·60
18. Stevenson—Ayrshire	1·3850	40·21	40·14	19·35	*	0·3	59·49
19. Lesmahagow—Southfield,	1·228	49·34	40·97	6·34	1·35	2·0	47·31
20. Knightswood,	1·234	44·77	41·13	11·05	*	3·05	52·18
21. Cairnbroe,	1·247	42·83	42·67	8·50	*	6·0	51·17
22. Skaterigg,	1·252	49·32	44·83	2·50	*	3·35	47·33
23. Cowdenhill,	1·299	46·0	45·0	5·0	0·50	3·50	50·00
24. Breadisholme,	1·335	39·0	48·5	8·1	0·4	4·0	56·60
25. Ruchill,	1·223	45·73	49·27	2·5	*	2·5	51·77
26. Kelvinside,	1·231	40·17	53·42	1·9	0·21	4·3	55·32

* Not estimated.

MEAN COMPOSITION OF AVERAGE SAMPLES OF SCOTCH AND VARIOUS OTHER COALS.

	Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
		A.	B.	C.	D.	E.	F.	G.	H.
Scotch Coals.	Wallsend Elgin,	1·20	76·09	5·22	1·41	1·53	5·05	10·70	58·45
	Wellewood,	1·27	81·36	6·28	1·53	1·57	6·37	2·89	59·15
	Dalkeith Coronation Seam,	1·316	76·94	5·20	trace.	0·38	14·37	3·10	53·5
	Kilmarnock Skerrington,	1·241	79·82	5·82	0·94	0·86	11·31	1·25	49·3
	Fordel Splint,	1·23	79·58	5·50	1·13	1·46	8·33	4·00	52·03
	Grangemouth,	1·29	79·85	5·28	1·35	1·42	8·58	3·52	56·6
	Eglinton,	1·25	80·08	6·50	1·55	1·38	8·05	2·44	54·94
	Dalkeith Jewel Seam,	1·277	74·55	5·14	0·10	0·33	15·51	4·37	49·8
Various.	Coleshill Co.'s Bagilt Main,	1·269	88·48	5·62	2·02	1·36	0·86	1·62	55·8
	Ewlowe,	1·275	80·97	4·96	1·10	1·40	8·20	3·37	54·5
	Ibstock,	1·291	74·97	4·83	0·88	1·45	11·88	5·99	50·8

AVERAGE COMPOSITION OF COALS FROM DIFFERENT LOCALITIES.

Locality.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Average of 36 samples from Wales,	1·315	83·78	4·79	0·98	1·43	4·15	4·91	72·60
" 18 " Newcastle,	1·256	82·12	5·31	1·35	1·24	5·69	3·77	60·67
" 28 " Lancashire,	1·273	77·90	5·32	1·30	1·44	9·53	4·88	60·22
" 8 " Scotland,	1·259	78·53	5·61	1·00	1·11	9·69	4·03	54·22
" 7 " Derbyshire,	1·292	79·68	4·94	1·41	1·01	10·28	2·65	59·32

AVERAGE COMPOSITION OF FOREIGN COALS.

	Locality.	Specific Gravity of Coal	Carbon.	Hydrogen	Nitrogen	Sulphur.	Oxygen	Ash.
		A.	B.	C.	D.	E.	F.	G.
Van Diemen's Land Coals.	South Cape,	—	63·40	2·89	1·27	0·98	1·01	30·45
	Mount Nicholas Break o'Day,	—	57·37	3·91	1·15	0·90	9·10	27·55
	Tingal,	—	57·21	3·38	1·20	1·32	7·80	29·09
	Jerusalem,	—	68·18	3·99	1·02	1·12	5·89	19·20
	Douglas River, East Coast,	—	70·44	4·20	1·11	0·70	9·27	14·38
	Tasman's Peninsula,	—	65·54	3·36	1·91	1·03	1·75	26·41
	Schonten Island,	—	64·01	3·55	0·94	0·85	3·38	27·17
	Whale's Head, South Cape,	—	65·86	3·18	1·12	1·14	7·20	21·50
	Adventure Bay,	—	80·22	3·05	1·36	1·90	4·80	8·67
	Sydney, New South Wales,	—	82·39	5·32	1·23	0·70	8·32	2·04
	Borneo—Lahman Kind,	1·28	64·52	4·74	0·80	1·45	20·75	7·74
	" Three-feet Seam,	1·37	54·31	5·03	0·98	1·14	24·22	14·32
	" Eleven-feet Seam,	1·21	70·33	5·41	0·67	1·17	19·19	3·23
	Formosa Island,	1·24	78·26	5·70	0·64	0·49	10·95	3·96
	Vancouver's,	—	66·93	5·32	1·02	2·20	8·70	15·83
	Lignite, Trinidad,	—	65·20	4·25	1·33	0·69	21·69	6·84
Chili Coals.	Conception Bay,	1·29	70·55	5·76	0·95	1·98	13·24	7·52
	Port Famine,	—	64·18	5·33	0·50	1·03	22·75	6·21
	Chirique,	—	38·98	4·01	0·58	6·14	13·38	36·91
	Laredo Bay,	—	58·67	5·52	0·71	1·14	17·33	16·63
	Talcahnano Bay,	—	70·71	6·44	1·08	0·94	13·95	6·92
	Colcurra Bay,	—	78·30	5·50	1·09	1·06	8·37	5·63
Patagonia Coals.	Sandy Bay, No. 1,	—	62·25	5·05	0·63	1·13	17·54	13·40
	" No. 2,	—	59·63	5·68	0·64	0·96	17·45	15·64

Having seen in the foregoing the ultimate constituents of the several varieties examined, and also the amount of coke which they afford when heated in close vessels, the next point that demands inquiry is the state or condition in which those elements are contained in the coal. It is the belief of many that common coal is compounded of a carbonaceous substance like anthracite, and a bituminous one; and it would appear, from the microscopical researches which have been made, that such is usually the case. When, however, the fusibility of good coal is considered, and the homogeneous mass which it yields upon exposure to heat is closely examined, one is led to infer that the carbon is not isolated, but combined with the other constituents in such a manner as to form a definite body. Doubtless, in some species of lignite the bituminous matter is partly distinct from the carbonaceous; this may be deduced from the considerable quantity of tar which they yield, and the friable porous nature of their coke. From many facts connected with the manufacture of gas and other products from coal, it must be evident that this substance is chiefly composed of various hydrocarbons, which suffer decomposition by heat, and which, from the circumstance that suitable solvents have not yet been discovered, remain unisolated. It is an authenticated fact that the more the amount of hydrogen in a coal exceeds that of the oxygen, the more fusible is the substance, and *vice versa;* but this surplus is not sufficient to account for its fusibility; the entire quantity is concerned in producing the effect. When the amount of hydrogen is small, the coal will not be so fusible as when the proportion is larger, although in the first case the ratio in which it stands to the oxygen may be much greater than in the second. If the absolute percentage of hydrogen is only about 2, there is little reason to expect that such a coal will undergo fusion when submitted to heat. Experiments have shown that it requires at least 3 per cent. of hydrogen in the substance, with as much oxygen as will combine with half of this to form water, to render it fusible under the influence of heat. Such a coal affords a very intumescent coke. Coals less inclined to melt than one so constituted may contain a variable amount of hydrogen; but when the proportion exceeds 1½ per cent. the oxygen will be required in quantities capable of transforming at least two-thirds of this into water. On the other hand, if the hydrogen and oxygen be exactly so proportioned in the coal as to form water, the coal will be infusible, and the coke which is left will be pulverulent. It is remarkable that many substances constituted of carbon, hydrogen, and oxygen, differ in this particular from coals; thus sugar, gums, starch, when submitted to heat, fuse and yield a compact coke. Hence it may be inferred that whether an organic matter containing about 48 per cent. of carbon, with oxygen and hydrogen to constitute water, shall be fusible or not depends on circumstances still requiring explanation. When the quantity of carbon exceeds 50 per cent., the substance is or is not fusible, according as the amount of hydrogen is or is not in excess above that which is necessary to convert the oxygen into water. All woody and fibrous matters are infusible, owing to their content of carbon being more than 50 per cent., whilst the oxygen and hydrogen making up the remainder are so proportioned as to compose water; there are, however, other bodies in which the carbon constitutes from half to nine-tenths of their weight, and yet they are fusible and even volatile under the influence of heat. Such is the case with some of the resins, wax, &c., which contain a large quantity of hydrogen that assimilates itself with the carbon, giving rise either to gaseous bodies or liquids, into which the latter largely enters. It is upon these grounds also that the explanation of the fusion of coals so rich in carbon as 80 per cent. rests.

In many branches of trade experience has pointed out the advantages which some varieties of coals afford, from the circumstance that the nature of their combustion is adapted to the special work assigned them. Hence the selection of gas coal, steam coal, and such like, on account of the respective qualities they possess; the former of producing large quantities of gas, the latter of yielding a high temperature, at the same time that its combustion is tardy and gradual. The first are evidently such as, when heated, enter more into fusion, as is obvious from the adoption of cannel in gas-works whenever it can be found. For generating steam, coals which are only slightly fusible, and bordering upon the nature of anthracite, are found from experience to be the best. For various other manufacturing purposes, the particular requirements of each must decide the fittest quality of fuel. In reverberatory furnaces, and such others as are constructed with the view of producing an effect at a distance from the fire, flaming coals will be found best adapted for the purpose, but not those which are apt to form a coherent cake in the grate, whereby the draught would be impeded, and the combustion be inadequate to the effect required. On the other hand, where the heat must be very intense, those coals are found to be the best which contain a large percentage of carbon, with as much hydrogen and oxygen as will generate sufficient quantities of inflammable gases to promote its rapid ignition, but at the same time not enough to effect fusion to any considerable extent. Such is the kind required in the smelting of metals, for the working of iron, &c.

Torbanehill, or Boghead Coal.—The peculiar characters of this substance, on the nature of which geologists and chemists were much divided, attracted very great attention several years ago, and led to important legal proceedings, arising out of the following circumstances. In the beginning of the year 1850 a contract of lease was entered into between the proprietor of the estate of Torbanehill, near Bathgate, Linlithgowshire, and the Messrs. RUSSEL, Falkirk, conveying to the latter, in consideration of a fixed rent, a right to the whole coal, ironstone, iron ore, limestone, and fire-clay, on the lands of Torbanehill, for a period of twenty-five years; but the lease was not to comprehend copper, or *any other mineral whatever except those above specified.* In the course of their researches, the Messrs. RUSSEL had previously found an extensive deposit of the Torbanehill coal, which was shown by Dr. PENNY, in 1849, to be invaluable as a coal for the manufacture of gas. As such it was worked and disposed of by the Messrs. RUSSEL. In these circumstances the proprietor of Torbanehill brought an action against the lessees for damages, on the ground that the substance was not coal at all, nor any of the minerals comprehended in the lease, and that, therefore, the lessees had no right to remove it. The case was tried at Edinburgh, before the Lord Justice-General and a special jury, in the months of July and August, 1853, and excited intense interest, both on account of the curious scientific question involved and the number of eminent professional authorities cited on both sides as witnesses. At the same time, the only material difference, with reference to the facts of the case, appeared in the results of the microscopical examination. The geologists and chemists agreed as to the constitution of the substance—they differed only in the name which they were inclined to give it, according to their special views of what constituted coal. The microscopical evidence was strongly in favour of the claim of the Torbanehill mineral to be considered a true coal; and this, in concurrence with the general analogies presented, induced the jury to return a verdict for the defendants. In this verdict, which quite harmonized with the opinion pronounced by Dr. Penny before the Torbanehill coal became a subject of litigation at all, there seems to be no difficulty in acquiescing. Among the recognized true coals there are infinite diversities in the relative proportion of the ingredients—from anthracite at one end of the scale, to cannel or parrot coal at the other; and the Torbanehill coal appears, from its composition, to be not less justly entitled to the name of a coal than anthracite, though standing at the opposite end of the scale.

In all its leading physical and chemical characters it is identical with other varieties of cannel coal. It is unquestionably of vegetable origin. It forms a seam varying in thickness from 16 to 21 inches. Its geological position does not differ from that of other Scotch cannel coals, and the associated rocks are similar to those that occur in other coal fields. In the upper part of the seam the colour of this coal is brown, and the streak light yellowish-brown; but in the lower part its colour is black. Fossil plants, especially stigmaria of various sizes, and with numerous rootlets, are found in every part of the coal. Some are in the shape of large trunks of trees, 1 or 2 feet in diameter.

The Occlusion of Gas in Coal.—What is known on this subject is due to the researches of Marsilly and Dr. Ernst von Meyer. The former of these investigators found that the evolution of gas commenced at about 50° C. and continued to 300° C., the amount of gas evolved amounted from 1 to 2 per cent. of the weight of the coal, and the gas evolved is either carburetted hydrogen or nitrogen. The subject has been more fully considered by Mayer, a short abstract of whose labours appears below. The nature of the gases disengaged from German and English coal was the subject of inquiry, and a lengthy table is published in the original paper, to be found in Erdmann's "Journal für Praktische Chemie," 1872, vol. cxiii. p. 407. The following table contains the results obtained with the English coals experimented on.

Name of Coal.	Number of Cubic Centimetres of Gas yielded by 100 Grammes of Coal.	Number of Cubic Inches of Gas yielded by 1 Pound of Coal.	Carbonic Acid.	Oxygen.	Nitrogen.	Marsh Gas.	Remarks.
I.—From the Low Main Seam, Bewicke Main Colliery,....................	25·2	6·975	5·55	2·28	85·65	6·52	Weathered.
II.—From the Maudlin Seam, Bewicke Main Colliery,....................	30·7	8·498	8·54	2·95	61·97	26·54	Hard conchoidal fracture.
III.—From the Main Coal Seam, Urpith Colliery,..........................	27·0	7·474	20·86	4·83	74·31	—	Bright fracture.
IV.—From the 5 Quarters Seam. Urpith Colliery, 3 fathoms from surface, ...	24·4	6·754	16·51	5·65	77 84	trace.	"
V.—From the 5 Quarters Seam, Wingate Grange Colliery, 74 fathoms from surface,..........................	91·2	25·245	0·34	trace.	13·86	85·8	Fibrous.
VI.—From the Low Main Seam, Wingate Grange Colliery, 108 fathoms from surface,..........................	238 0	65·882	1·15	0·19	14·62	84 04	
VII.—From the Harvey Seam, Wingate Grange Colliery, 148 fathoms from surface,..........................	211.2	58·463	0·23	10·55	9·61	89·61	Hard, conchoidal fracture, coated pyrites.
VIII.—From the Harvey Seam, Woodhouse Close Colliery, 25 fathoms from surface,......................	84·0	23·252	5·31	0·63	44·05	50·01	

As will be seen, these coals contained gas consisting of carbonic acid, oxygen, nitrogen, and marsh-gas. Some of the German coals contained, in addition, hydride of ethyl, carbonic oxide, and gases absorbable by sulphuric acid. Fresh-gotten coal appears always to give more gas than old gotten, but the age of the coal in the bed appears to have no effect upon the result. It has been a question how the nitrogen is occluded. Bischof held that it was produced by slow decomposition of organic matter. Now Meyer, on the other hand, shows that free nitrogen does not result from decay, and that it is more likely to have been derived from the atmosphere.

With reference to the English coals analyzed, Professor Freire-Marreco says, that on considering the analyses of the gases given off by the fresh coals, they divide themselves at once into two very distinct classes, one of which contains a mere trace of marsh gas (one specimen, indeed, contained none at all); the other class yielding a considerable amount, so that these analyses show that which has been long known practically, that there is a very great difference between a fiery and a non-fiery coal. It might be well worth noting here that Dr. Meyer's analysis shows that, in the same seam (five-quarter) of two different pits, one pit gives coal containing a mere trace of marsh gas, while the coal in the same seam in another pit contains 86 per cent of marsh gas. This seems interesting. Then, as to the volume of the gas, there is a much greater variation in the English coal than there is in the German; the maximum is 3·09, the minimum ·32, a difference of something like 1000 per cent.; and the mean is 1·089. Dr. Meyer does not appear to have made any examination of the effect of weathering upon the English coals. His analysis is exclusively confined to the gases given off by the coal in the condition in which he got it, which may or may not have been more or less weathered. He also appears to have made a further series of experiments on German coals, upon the effect of exposing the coal for a short time (twenty-four hours) to the action of a temperature of 50° C. After that exposure he promptly heated the coal more strongly, and apparently found a higher term of the marsh gas series.

The weathering of coal has been experimented upon, from which it appears that it is a variation of temperature in coals exposed to the atmosphere which affects them, and that when retained in a uniform temperature there is no appreciable variation in a subsequent analysis even after a year or more. The principal changes that take place are a combination of the carbon and hydrogen of the coal with the air, forming carbonic acid and water, whilst a certain amount of oxygen and nitrogen appears to enter into mechanical combination with the coal, whilst, if the coal contains pyrites, a certain quantity is oxidized. All these influences, of course, diminish the value of the coal as fuel.

Colliery Explosions.—The phenomena called colliery explosions are due to the combustion of mixtures of air and fire-damp, of air, fire-damp, and coal dust, and perhaps also, under certain conditions, of air and coal dust alone, in the workings of mines. They do not result from the operation of unknown laws; but, on the contrary, the causes which produce them, and the manner in which they operate, are both well known. These causes are various, and act sometimes independently, sometimes in conjunction with each other; and therefore, in order that we may be able to give a concise description of the subject, it will be of advantage to consider the different parts of it separately, and to point out the relation which they have to each other. This may be done in the following way:—

1. *On the Composition and Mode of Occurrence of Fire-damp.*—Marsh gas (CH_4) is the principal constituent of fire-damp, but it is mixed with various proportions of oxygen, nitrogen, carbonic acid, carbonic oxide, and occasionally perhaps a trace of some other hydrocarbon.

The following analyses have been made within the last three years, and the gases which they represent may be accepted as typical specimens, showing a widely varying composition. They were obtained from *blowers* in the following collieries:—I. Barleith, Ayrshire; II. Hebburn, Newcastle; III. Llwynypia, South Wales; IV. Dunraven, South Wales.

	I.	II.	III.	IV.
Marsh gas,	75·86	85·22	94·78	97·65
Olefiant gas,	—	trace.	—	—
Hydride of ethyl,	—	—	0·90	—
Carbonic acid,	1·31	3·27	0·72	0·50
Carbonic oxide,	—	1·36	—	—
Nitrogen,	22·83	7·98	3·60	1·85
Oxygen,	—	2·17	—	—
	100·00	100·00	100·00	100·00

Fire-damp is contained in coal seams, where it was undoubtedly formed during the gradual changes which the original vegetable matter has undergone during its transformation into coal. It escapes into the workings of mines through the small fissures which abound in coal seams and the strata adjoining them, and is either carried away in a diluted state by the ventilating currents, or, mixing with the air in cavities in the roof and in unventilated spaces, forms inflammable accumulations.

The rate at which this escape takes place is entirely dependent on the pressure of the atmosphere already occupying the space into which it flows. For instance, it may be assumed that each unit of volume of coal contains a certain definite weight of fire-damp, which ultimately escapes into the atmosphere; moreover, the tension of the fire-damp is appreciably higher, and sometimes very much higher than that of the air. The simplest conceivable case is that of a seam extending over a large area, situated at a uniform depth from the surface, and covered over by a series of beds which preserve everywhere the same character throughout the area under consideration. Then, since coal is always more or less intersected with fissures (cleat), there is no reason why the tension of the gas should not be the same at one point of the seam as at another. Let a shaft be sunk from the surface, however, until it intersects the coal at a given point, and then we have a small area of lower tension, surrounded by an indefinitely large area of higher tension. Accordingly, the fire-damp flows into the shaft freely at first, and then more slowly, as it has to come from a greater distance, in consequence of the supply of gas in the nearer parts of the seam becoming exhausted. After this process of exhaustion has been going on for a time, we find that the pressure in any given fissure varies from point to point directly with the distance of each point from the shaft, until we reach a point at which it is still the same as it was before the shaft was sunk. After a further lapse of time, everything else remaining as before, the point of normal pressure is found to be at a greater distance from the shaft, and so on.

The difference between the normal pressure of the fire-damp in the coal and the atmospheric pressure represents the dynamic head. But the friction which the gas encounters in the fissures, or narrow channels, through which it has to pass, produces a loss of dynamic head in the gas issuing into the air, and consequently reduces the velocity of outflow to a corresponding extent. The amount of friction varies, however, with the distance through which the gas has to traverse these fissures; and, therefore, suppose we drive a heading into the coal seam from the bottom of the shaft, and follow the line of one or more of these fissures, we are continually tending to reduce the distance between the point at which the gas retains its normal pressure and the point at which it escapes into the air, and thus we have always more fire-damp flowing into a heading which is making progress than into one standing still. The rate of flow at any moment being, *cæteris paribus*, dependent on the value of the dynamic head, it is obvious that if that head is increased or diminished in any way, such as by a variation of the atmospheric pressure, the rate of flow must also vary; and it is found to be the case in mines that fire-damp is more prevalent during the continuance of a low barometer than in the opposite case.

Much evidence has been given before parliamentary committees for the purpose of establishing this fact, and several papers have been recently published to show that explosions are for the most part coincident with sudden barometric depressions. Some of these have been contributed by R. H. SCOTT and W. GALLOWAY (*Proceedings of the Royal Society*, vol. xx. p. 292, and *Quarterly Journal of the Meteorological Society*, vol. i. No. 8, and vol. ii. p. 195), and to them we would refer the reader for fuller information on the subject.

In the plate accompanying the last-mentioned paper a curve is given which proves undoubtedly that fire-damp escapes most plentifully when the barometer is low. It is the first curve of the kind that has been published, and probably the only one up to the present time. Fig. 24 is the reproduction of part of this curve. The thick undulating line represents the barogram at Glasgow during the months of October, November, and December, 1873; and the thin line above it, which rises and falls in evident sympathy with the former, indicates the number of mines, out of a total of thirty-five, in which fire-damp was found from day to day throughout the same period. The spaces between the vertical lines represent days; Sundays are indicated by thick horizontal lines near the base; the number of mines in which fire-damp is found on any particular day can be ascertained by means of a scale at the left-hand side, measuring downwards; and the height of the barometer is shown by the other scale at the same side, measuring upwards.

Fig. 24.

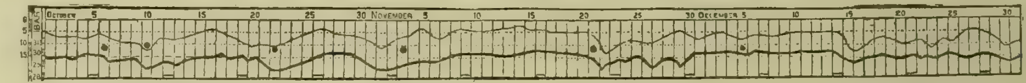
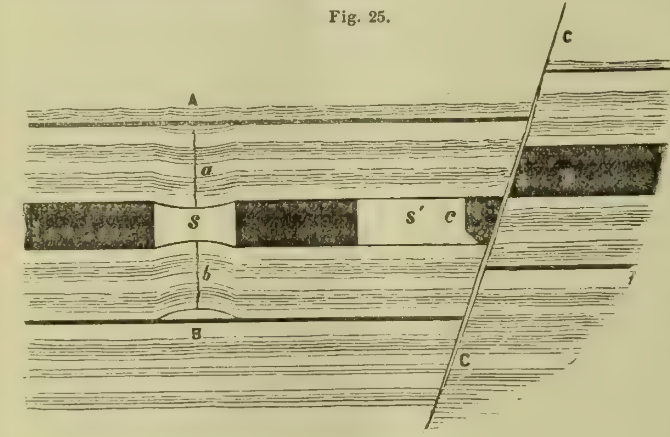


Fig. 25.



There were slight explosions of fire-damp in the West of Scotland mines on the 6th, 10th, and 22nd of October; on the 3rd and 21st of November, and on the 5th of December: these dates are specially marked on the figure by means of dots.

Besides altering the rate of flow in the manner just indicated, changes of atmospheric pressure produce expansions and contractions of volume in accumulations of fire-damp which are lying inactive, or have an inappreciable outward movement in open fissures, cavities in the roof, old workings, &c. The boundaries of such accumulations are naturally near a ventilating current, or a point at which they can escape by diffusion; and hence, every time their volume is expanded, they contribute more fire-damp to the ventilating currents than at ordinary times, and so tend to disturb the general equilibrium.

Sometimes large volumes of gas are rapidly given off in the workings of mines: and when the ventilation is not very good at the point of their appearance, they may have the effect of making the air in the neighbourhood explosive. Such eruptions are not of common occurrence; indeed, they may be said to be exceedingly rare.

They arise from two different circumstances, both of which are represented in Fig. 25. This figure shows a vertical section of strata containing three seams of coal, A, B, and the thick seam between them. S and S′ are workings in the latter. The roof and floor are supposed to have bent down and upwards respectively into the space S, causing the formation of small cavities at A and B, in which fire-damp accumulates with the normal tension of that contained in the seams A and B. At length a rent, *a* or *b*, takes place, and the pent-up gas escapes into the workings. On the other hand, C is intended to represent a natural fissure —in this case a dislocation—of which the sides are not close together and the space between them has not been filled up, as usual in the case of most faults. Here the fissure is supposed to be open only locally, so that gas escaping into the cavity from the various coal seams remains there at the pressure at which it existed in these seams. Accordingly, when the working, S′, approaches it, the block of coal, *c*, is either burst off violently, if the pressure is great enough, or the gas is tapped by the miners when they are undermining this block previously to removing it.

2. *Some of the Properties of Fire-damp.*—If fire-damp is made to issue into the air as a jet it can be ignited by the application of a flame, and burns like ordinary gas. Its flame is pale blue and tipped with white,

the proportionate magnitude of the white part being greater or less according to the size of the jet. When mixed with certain proportions of air it forms inflammable mixtures, which burn quietly or explode, according to their composition. It is usually said that 14 volumes of air is the greatest quantity that can be mixed with 1 volume of fire-damp so as to form a mixture which is still inflammable at ordinary temperature. This statement is not strictly correct, however, and it may be said in a general way that these proportions are *entirely* dependent on the composition of the fire-damp. For instance, the gas whose analysis is given first in the table on page 947 did not form an inflammable mixture with air when the relative volumes were 1 to 13, whereas the third gas formed such a mixture when the volumes were 1 to 15. In a similar manner it might be shown that the proportions of air and gas in the most inflammable or most explosive mixtures are also dependent on the composition of the fire-damp.

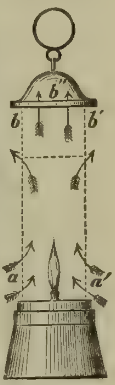
These facts have usually been overlooked in descriptions of experiments with fire-damp, and it ought to be borne in mind that such experiments, if conducted with gas taken from different localities, are not comparable with each other unless the analysis of each gas is given.

To mention one instance: In the "Annales des Mines," 1875, tome vii. p. 355, there is a paper by E. Mallard which discusses the question of the velocity with which flame traverses mixtures of fire-damp and air. The results of experiments are given which were made to test this point, and Mallard founds certain conclusions on them. One of these conclusions is that, if the ventilating current of a mine having a velocity of 1·968 feet per second became explosive, and were ignited at any point of its course, the flame could not travel backwards against the current. It must be observed, however, that the diameter of the jet of inflammable gas employed was only 0·216 inch, and therefore it would be exposed to proportionately much greater cooling effects than if it had a diameter of several feet; but apart from this consideration, it appears that the most diluted mixture that was still inflammable consisted of 12 volumes of air to 1 of gas, showing plainly that the fire-damp was an impure one. It seems, therefore, to be scarcely justifiable to draw general inferences from these experiments; and it is to be regretted that the analysis of the fire-damp is not given, so that they might at any rate have some definite value.

In considering phenomena connected with the combustion of mixtures of gas and air it is necessary to have special regard to three temperatures; these are the *initial* temperature, and the temperatures of *ignition* and *combustion*. The last may be called the *final* temperature. It may be set down as a postulate, perhaps, at least for the purposes of this article, that for combustible mixtures such as those we are now considering, the temperature of ignition is constant, and the interval between the initial and final temperatures is also constant at constant pressure. The temperature of ignition of mixtures of fire-damp and air has not been accurately determined, but it may be stated to be somewhere between a red and a white heat (700° and 1000° Fahr.). On the other hand, the final temperature depends both on the initial temperature and on the composition of the mixture. Thus it is that when the proportion of inert gases is least the final temperature and the velocity of flame through the mixture are greatest; or, in other words, the mixture has its highest degree of explosibility. As the mixture is diluted, however, by the addition either of air or fire-damp, its final temperature decreases until it is the same as that of ignition; and by a further dilution it is rendered non-inflammable for a given initial temperature.

The final temperature of an inflammable mixture may be reduced by the close proximity of a cooling body; and it is evident that if the temperature of the cooling body be maintained at a lower point than the temperature of ignition of the mixture, those particles in immediate contact with it will not be able to enter into combustion. Sir H. Davy took advantage of this property in his invention of the safety lamp. In its simplest form that contrivance consists of an ordinary oil lamp, surmounted by a cylinder of wire gauze closed at the top. The air necessary for combustion enters at *a*, *a'*, Fig. 26, and the products of combustion escape at *b*, *b'*, *b''*. When this lamp is placed in an atmosphere in which the quantity of fire-damp is very small at first, and is gradually augmented until it is largely in excess, the following phenomena are observable in succession. The flame having been made small, so as to reduce the amount of yellow in it as far as possible, burns at first as in pure air; as the quantity of fire-damp increases it assumes a small pale blue conical cap; the cap increases in size, and becomes spindle shaped; it stretches to the top of the wire gauze cylinder, and spreads out, having the appearance of an inverted cone with its apex resting on the wick; it fills part of the cylinder at the top, and gradually draws downwards until it forms an inside lining to the gauze cylinder. This lining is bright blue, and appears to be about one-eighth inch thick when observed from above—the oil flame still burns inside. The oil flame goes out after this, and no alteration takes place until at length the lining gathers itself to the top again, where it burns with a lurid glow and a kind of spherical shape; and at last this flame also goes out, when the temperatures of ignition and combustion are rendered the same by the superabundance of fire-damp.

Fig. 26.



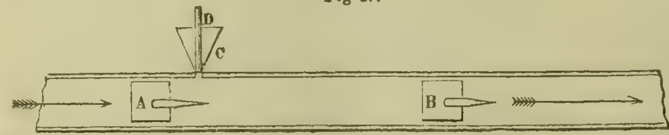
The combustion going on inside does not heat the wire gauze cylinder to the temperature of ignition of the gases, since the heat imparted to it from within is partly radiated into surrounding space, and partly carried away by convection; and hence it is that, although portions of inflammable mixtures are passing freely inwards through the apertures, the flame is not conducted to the outside. Two circumstances may arise, however, under which the flame may be forced through the apertures of the ordinary gauze lamp, and thus communicated to the external gases. These are—1, when an inflammable current is directed against the lamp with a velocity of 7 to 8 feet per second; and, 2, when an intense sound-wave from a blown-out or overcharged shot traverses such a lamp, which has been placed in an inflammable mixture by accident or otherwise. The former phenomenon has been known for many years; the latter has been demonstrated by experiments, described in the "Proceedings of the Royal Society," No. 154, 1874.

Until recently, colliery explosions have been always attributed to the combustion of *inflammable* mixtures of air and fire-damp; that is to say, of mixtures which of themselves were inflammable at ordinary pressure and temperature. On several occasions it has been suggested that the dry coal dust, which is plentiful on the floor of many mines, has no doubt been raised up by the force of the explosion, and, being subjected to the heat of the fire-damp, has given out gas which doubtless augmented the force of the explosion.

Two papers have lately appeared, however, which claim a new and hitherto unthought of *rôle* for coal-dust. The first (by Vital, "Annales des Mines," 1875) suggests that a mixture of coal dust and air alone is inflammable; whereas in the second ("Proceedings of the Royal Society," No. 168, 1876), experiments are described which tend to show that a mixture of air and coal dust alone is not inflammable at ordinary temperature; but that if air containing less than 1 per cent. of (the Llwynypia gas was used in the experiments) fire-damp has dry coal dust mixed with it in considerable quantity, it becomes inflammable, and can propagate ignition. The experiments by which this fact was proved were made in the following manner:—

Fig. 27 is a sketch of the apparatus employed. It consisted of a long wooden box, 18 feet 9 inches long, by 12 inches deep, by 6 inches wide inside; provided with two windows, A and B, a hopper, C, into which coal dust was put, and a plug, D, by means of which the coal dust could either be retained in the hopper or stirred gently, so that it fell through into the apparatus. A current of air and fire-damp, well mixed, was made to traverse the apparatus in the direction of the arrows, and its velocity and composition were both under control. Two open lights were placed in the apparatus opposite the windows, so that they might be easily observed. This was done while the current was traversing the box, and after it had been ascertained *not to be explosive*, by means of a safety-lamp. The flames of these lights were seen through the windows, and any changes could be instantly observed. It was found by many experiments in this apparatus, and in another similar one described in the paper already referred to, that coal dust and air alone were not inflammable under the conditions described; but that when a small proportion of fire-damp was added, the mixture became inflammable or explosive, according to the proportions of fire-damp and coal dust contained in it. When the mixture of air, coal dust, and fire-damp was inflammable, it ignited at the open flame, B, while the mixture of air and fire-damp alone passed the flame, A, without seeming to affect it. The smallest proportion of fire-damp employed with this result was 0·892 per cent. of the volume of the mixture, or the relative volumes of gas and air were 1 to 112·06.

Fig 27.

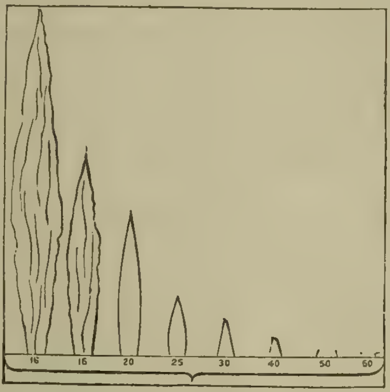


It is thus evident that a new factor must be taken into account in reasoning regarding colliery explosions; and in the case of dry mines it is no longer necessary to suppose that an actually explosive accumulation of fire-damp and air has been formed, or has existed previous to an explosion; since, if we could trace the existence of causes which tended to raise the coal dust into the air, and could show that that air already contained a small percentage of fire-damp, we have already obtained all the elements necessary to produce an explosion on the application of a flame. How this flame is usually applied in the case of explosions in mines will form the subject of some remarks further on. Before leaving the discussion of the properties of fire-damp, it will be necessary to complete it by referring to the properties of non-explosive mixtures of this gas with air. Little or nothing has appeared hitherto in elucidation of this part of the subject. However, in the paper to the Royal Society just referred to, there are certain results given which leave the matter no longer in obscurity. These results were obtained by means of a series of experiments with the Llwynypia gas, and consist of the tabulation of observations regarding the height of "cap" produced on a lamp-flame of given dimensions by mixtures of fire-damp and air whose composition varied from 1 gas to 16 air up to that of 1 gas to 60 air. The intermediate mixtures were 1 to 18, 20, 25, 30, 40, and 50. "The cap," according to the words of the paper from which we are quoting, "is a spindle-shaped or conical blue flame, more transparent than and appearing to rest upon the oil-flame; it seems to be due to the combustion of that part of the mixture of fire-damp and air which becomes heated to the temperature at which its active constituents can combine." That is to say, it is due to the combustion of as much of the mixture as becomes heated to the temperature of *ignition* by contact with the oil-flame. It is unnecessary in this place to describe the kind of apparatus by which these results were obtained; and it is sufficient to say that the oil-flame employed in the observations was identical with that usually employed in mines when small proportions of fire-damp are searched for. In this case it was about one-fourth of an inch in diameter by one-eighth of an inch high, and had a conical speck of yellow near the top. The caps were observed in total darkness, and their heights were measured by means of a scale placed immediately behind them. They were also sketched at the time, so that a record of the form of each might be preserved.

Figure 28 shows the forms and dimensions of these caps reduced to half their natural size. By observing the height of "cap," therefore, in any airway, and referring to this diagram, we are in a position to ascertain in a sufficiently approximate manner what proportion of fire-damp is contained in it; and thus we can judge whether the air-current is near or far from the explosive point. It is worthy of remark here, that if a diagram be constructed with its base-line divided so as to represent the volumes of air mixed with one of fire-damp, and the lengths of the ordinates the heights of the caps, the curve which is obtained by joining the extremities of the ordinates is approximate to the form of a rectangular hyperbola.

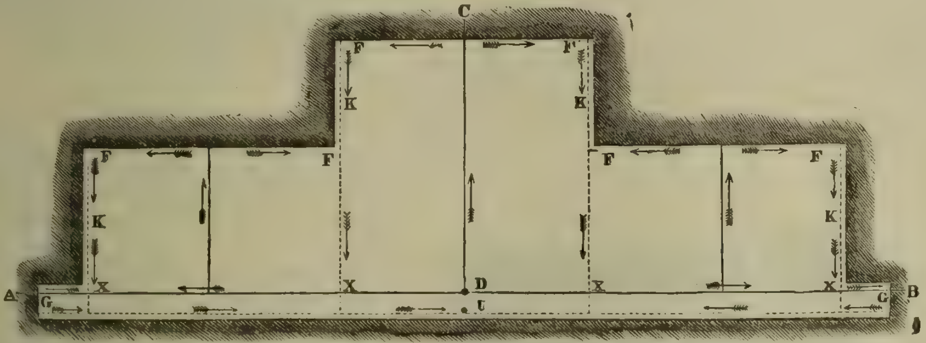
3. *On the Manner in which Explosions are Originated.*

Fig. 28.



With the aid of Fig. 29 the general principles pursued in working and ventilating mines may be explained.

Fig. 29.



In this figure all the superincumbent strata are supposed to be removed, so that we can see the coal seam and the workings in it. The plane in which the seam lies has a certain inclination from C to D U, C being the highest point; while the line G G or A B is horizontal. The internal space represents the workings in which the coal has been either wholly or only partly removed. The dark surrounding space is the still untouched coal: D and U are two shafts sunk from the surface to the coal seam; F F, F F, and G are the places from which coal is being obtained, or the working places, F F, &c., which are called faces sometimes, are progressing in the direction D C; those marked G are progressing towards A and B; and those marked K are standing still, that is to say, no coal is being removed from them.

It is necessary to have a current of air continually passing along each working face to dilute and remove the fire-damp which escapes from the solid coal, and also to provide for the respiration of the workmen. To this end certain main galleries are maintained through the workings, so as to preserve a communication between the working faces and the atmosphere at the surface, through the medium of the shafts. These galleries are shown by plain and dotted lines in the figure; those shown by plain lines are seen to set out from the bottom of the shaft, D, while the others set out from the shaft, U. At the points X X, where they cross each other, the galleries represented by the dotted lines are taken over the top of the others, being separated entirely from them by means of arches or any other convenient arrangement. It is thus seen that if a draught is created in the shaft, U, by kindling a fire at the bottom, or by putting the top in communication with an exhausting fan, the air will pass down the shaft, D (*downcast*) from the surface, traverse the airways represented by the plain lines (*intake* airways), pass along the working faces, enter the airways represented by the dotted lines (*return* airways), and through them gain access to the shaft, U (*upcast*), from which it is ejected into the atmosphere at the surface. The various directions of the air in each set of airways and at the faces are shown in the figure by means of the arrows. It should be explained that when the mode of removing the coal is such that the spaces between the airways are not filled up, the airways themselves are isolated from that space, and therefore from each other, by building walls (*stoppings*) in each of the openings which branches from them.

The arrangement of workings described above is a perfectly arbitrary one; there is no reason why the faces, K K, should not also progress, and we have chosen to consider them stationary only for the sake of simplicity in the explanation; moreover, the faces, F F, which do progress, are not necessarily straight lines except in the case of longwall workings.

We shall now consider in greater detail the two most common methods of working practised in seams of medium thickness, as far as the arrangements at the faces are concerned. We shall take one working place as an illustration of each method, remembering, while doing so, that each of the faces, F F, &c., of Fig. 29, may be made up of a large number of such places; indeed, when these faces, F F, are extensive, they are often referred to as separate districts of the mine.

Fig. 30 shows the plan and section of an ordinary working place according to the "bord and pillar," or "stoop and room" method; and Fig. 31, those of part of a *wall* according to the "longwall" method. The course of the air current is shown by the arrows in both cases. In Fig. 30 the direction is from *c* to *e*, but a *brattice* or partition consisting of thin boards or of canvas nailed to props, *p p*, changes it and compels the air to sweep the face, *g*, at which most of the fire-damp is given off. Coal is only removed at *g* during this part of the process, and rectangular blocks of coal are left to support the roof; *s* is a stopping built between the two last pillars for the purpose of confining the air to the course which it is intended to take; *d* in the section is a door in the brattice for allowing haulage to be carried on along the tramway, *c e*; and *f* is a cavity in the roof from which a block of stone has fallen. As we have said, the principal part of the fire-damp is given off at *g*, the face, although, as might be expected, some also exudes from the fissures in the sides, roof, and floor of the working place. Accordingly, if the door, *d*, is accidentally left open or damaged by any chance, the air-current goes direct from *c* to *e*, and fire-damp collects at *g* and in *f*, the highest points in the place. Now suppose that the workmen have open lights, and that they have been absent for a short time in some other part of the workings, on their return they may and usually do observe the defect, and so refrain from going as far as the face; but, on the other hand, for one reason or another, they may consider that the probability of fire-damp having collected during their absence is excessively small, and so they proceed towards *g*, and ignite the gas.

Fig 30.

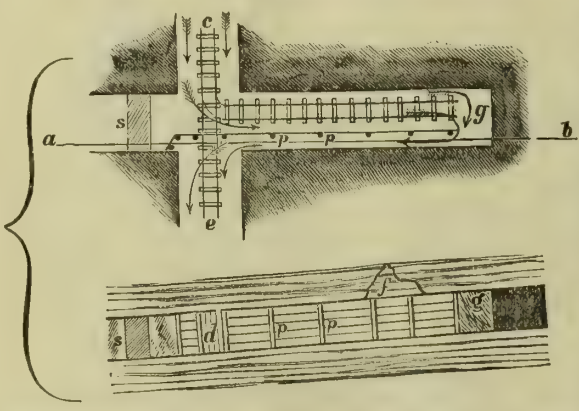
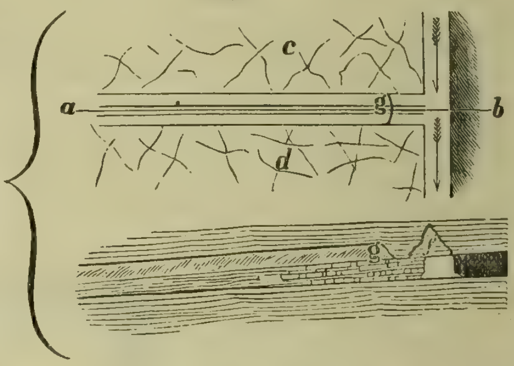


Fig. 31.



Referring to Fig. 31, now, it will be seen that the coal is all removed at one working, and the roof settles down on a packing, or filling-up, of stones and rubbish, *c d*. The air can proceed directly along the face, and is independent of a brattice with a door in it. In this figure it is supposed that roof has to be cut to make room for haulage, and the part ripped down extends from the end of the figure at *a* to *g*. *f* is a cavity in the roof produced by a fall at the face. In this case, as in the last, fire-damp exudes principally from the face, but also to some extent through fissures in the roof and floor, even at considerable distances back from the face. It is therefore exceedingly common to find fire-damp in the cavity, *g*, which is an almost necessary accompaniment of longwall workings. At all events, when fire-damp collects at all, at or near to the working places, it appears first in the cavities, or highest points in the roof, *f* and *g*, and it is by the accidental ignition of gas which has accumulated in these positions that by far the greatest number of slight explosions are caused.

The manner in which these explosions occur may be stated as follows:—In the morning, before the workmen are allowed to proceed to their working places, an officer, called a *fireman*, examines every part of the mine in which work is to be carried on; he uses a safety lamp only, and tests all the cavities, such as *g* and *f*, to detect fire-damp, lest any should have collected in them during the night. Supposing now that he has found no fire-damp, and that the men proceed to their places with open lights, there is not much opportunity for fire-damp to accumulate during the day on account of the constant commotion in the air caused by the movements of the workmen in their places; this motion of the air helps to disperse the gas, and promotes diffusion.

So long, therefore, as everything remains in the same condition as it was during the night and in the morning, there is no probability of an explosion taking place; but as soon as one of the trap-doors is allowed to remain open for a little time, or the ventilating current is neglected, or the quantity of fire-damp exuding from the strata is increased by a fall of the barometer, a new state of matters is introduced; and if, in addition to the operation of one or more of these causes, the workman leaves his place for a little time, half an hour or an hour, some explosive gas *may* collect, and on his return he ignites it and is more or less severely burnt.

The majority of slight explosions appear to take place exactly as we have indicated; and 50 per cent. of all explosions are found to occur when the barometer is falling, or has reached its lowest point, or shortly after it has begun to rise again.

For the purpose of giving an idea of the relative number of slight explosions and serious ones, as well as to indicate the numbers of men killed and injured by these occurrences, we have extracted the following table from a paper published in the *Quarterly Journal of the Meteorological Society*, p. 196.

Year.	Fatal.		Non-fatal.
	Number of explosions.	Number of men killed.	Number of explosions.
1871	52	268	(234)
1872	70	163	(224)

The figures in brackets are estimated from data given in the original.

When fire-damp is persistent in a cavity in the roof, some attempt is usually made to clear it out by hanging a sheet of canvas in the roadway immediately below it, in order to deflect the air current up into it; and if, under ordinary circumstances, there does not happen to be an air current of sufficient velocity to effect this, travelling along a roadway in which such a cavity exists, measures are taken to divert more air than usual along it.

In mines in which safety lamps are employed exclusively, slight explosions of the kind we have been discussing seldom or never take place. For when fire-damp accumulates in a cavity in the manner already described, the workman discovers its presence by means of his safety lamp, and therefore the risk of its being ignited is very small. Nevertheless explosions occasionally occur in mines of this class, and it may be said that, as a rule, they are much more destructive to life and property than those which happen in mines in which naked lights are used. Why this should be the case is not very evident at first sight, when we take into consideration the fact that work is never carried on in an explosive atmosphere, and that as much care is usually taken to clear out small accumulations of fire-damp in these mines as in the others. Undoubtedly the quantity of fire-damp given off by the coal and strata in these mines is usually much greater in the aggregate, and consequently the amount of air employed to ventilate them is also greater than in the class of mines first referred to. They are sometimes called *fiery mines* on this account.

For many years the terribly destructive explosions which occurred in them from time to time seemed completely to baffle all attempts at an explanation, and even within the last few years they have been commonly attributed to the evolution of a large quantity of fire-damp at the very instant when some light was exposed or a shot was fired. The sudden irruption of fire-damp was generally considered necessary to account for the magnitude of the disasters, as it was thought that the ignition of none of the accumulations known to have existed in the mine could satisfactorily do so. This hypothesis is, however, entirely at fault when two districts of a mine, ventilated by separate air currents, can be shown to have been traversed by the explosion simultaneously, and to bear traces of fire in their innermost recesses.

It would be obviously absurd to suggest that an irruption of gas had taken place and been ignited in each district at the same time, since these occurrences are very rare. Another explanation must therefore be sought; and if it accounts for cases of *apparently* double or treble explosions in the same mine, why should it not be accepted as accounting for ordinary explosions as well?

Such an explanation has been suggested in the paper already quoted, "On the Influence of Coal Dust in Colliery Explosions." Our space does not, however, permit of our pursuing the subject further; and we will only add in concluding, that it will be an object of much importance to ascertain the relative numbers of *great* explosions that have taken place in mines containing plenty of dry coal dust and in those containing little or none.

COKE.—Like wood and peat, coal has been found unadapted for many purposes in its natural state; either the heat which it evolves is insufficient from the presence of water and other ingredients, or the same effect is produced by the tendency of most coals to fuse and form a coherent mass, whereby the air is excluded and the combustion impeded. Although the latter is the most frequent cause of failure, both contribute to render coals inapplicable to the wants of many of the arts and manufactures. To obviate these difficulties, and to bring the coal to a state in which it will yield the greatest possible amount of heat, recourse has been had to carbonization. By this operation, the principles of which have been already explained, the volatile bodies are expelled and the liquid bodies decomposed, so that their carbon becomes to a great extent fixed, whilst the hydrogen and oxygen are dispersed. These volatile matters are utilized or not, according to the circumstances and the locality in which the carbonization is carried on. Thus, when the operation is conducted in large towns the gases become not only a source of profit to the persons engaged in the trade, but of comfort and safety to society by their illuminating power. In localities which are not populous, or which are far removed from cities and towns, these valuable products are permitted to pass off, not only uselessly, but often injuriously to animal and vegetable life. In either case the fixed matter left is known as coal-charcoal or coke.

The carbonization of lignite is a subject of but little interest to manufacturers, in consequence of its use being so very limited. We will therefore proceed to the consideration of pit charcoal, which is of vast importance to every country.

The extensive variety of coal met with necessarily suggests a corresponding difference in the effects produced by the action of heat upon them, and it is to be expected that the products should indicate similar differences. All coals which are in any degree bituminous yield three classes of bodies—namely, the residuary matter, containing carbon in excess; the liquid substances, which are in like manner very carbonaceous; and the gaseous bodies, of which there are several. It is almost needless to remark that the proportion of the second class will be dependent upon the fusibility of the coals; and even the third is chiefly derived from fusible or caking coals. As a general example of the nature and relative proportions of these three varieties of products, the following analysis may be taken:—

		Centesimally.
	Coke,	68·925
Liquid products.	Tar,	12·230
	Water,	7·569
Gaseous products.	Light carbide of hydrogen,	7·021
	Carbonic oxide,	1·135
	Carbonic acid,	1·073
	Olefiant gas,	0·753
	Sulphide of hydrogen,	0·549
	Hydrogen,	0·499
	Ammonia,	0·211
	Nitrogen,	0·035

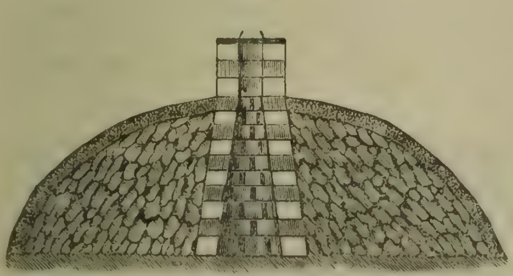
While the absolute and relative yield of these products depends chiefly on the composition of the coal, the method and management of the operation to which they are submitted exercises a marked influence. Thus it may be seen practically that the products differ to the extent of several units per cent., according as the heat applied in the charring is low and gradual, or elevated and rapid. In the amount of coke, which constitutes by much the largest product, or more correctly, the residue, the observed variation from this cause is sometimes so high as 6 per cent., but generally it ranges from 3 to 4 per cent. It is not only in quantity, however, that the mode in which the heat is applied produces a marked effect, the quality is liable to not less variation from the same cause. By the application of a low prolonged heat, gradually raised till it reaches the strongest red heat towards the completion of the carbonization, the coke is more compact, from the circumstance that the fusion of the coal is more perfect under the gradually increasing temperature, than if the latter were applied suddenly in full force. As a general rule, these matters are little attended to in the British coke districts, the coal employed being so bituminous as to yield, under either of the conditions above stated, a compact mass, which can endure the effects of carriage without sustaining much injury.

The several methods in use for the charring of coal, for whatever purpose, may be comprehended under three heads—namely, distillation in close vessels; heating in open heaps; and a method in which the principle of both is to a certain extent brought into requisition.

Of the first mode it is sufficient to say, in addition to what has been already stated, that the coke so produced is not only limited in amount, but is of such a nature as to render it inefficient where a very compact dense fuel is required, as in the iron furnaces and the like. Indeed, when close distillation is resorted to, the coke is less an object of consideration than the liquid and volatile products; and therefore it will be more in keeping with the plan of this work to speak of it hereafter under the article GAS. By the second method, the advantage is gained of preparing a large quantity of the fuel in a short time, but at the loss of considerable quantities of material, as will be seen afterwards. The third method, in which a furnace of a special form is employed, and which admits of operating upon a large quantity of coals at once, is that which is daily becoming recognized as the most economical, for it operates quicker, with less loss, and requires less attention than the others.

Coking by the second method, or the open heap, requires nearly the same operations as the carbonization of wood, only that the mounds are not so large, and they require less attention. Two systems are followed, the one characterized by the round heap or pile process, and the other by the coals being arranged in rows or ridges. For the purpose of coking in heaps, a level plot of ground is selected, the area of the heap marked out, and the coals piled upon it, placing the larger pieces at the base, and so on to the top. Fire is then applied in a cavity of about a foot in diameter, which is formed in the top for this purpose, and the carbonization allowed to proceed. In a short time the entire mass is covered with the fire, owing to the combustible gases which are discharged, and which, igniting, conduct the fire over the whole of the coals, at the same time that they prevent its loss by shielding the heated solid carbonaceous matters from contact with oxygen. When the whole mass is at a red heat, or nearly so, and the dense heavy smoke which is emitted as long as the decomposition of the volatile ingredients in the fuel is actively proceeding has ceased, a light coating of coke ashes, or the rubbish which has accumulated, is thrown on, and the air entirely excluded. Sometimes the mound is covered with straw, dried leaves, or brambles, and coke dust or clay, before it is ignited; but this is not generally thought necessary, as the density of the coal and the downward progress of the fire, till it reaches the base of the heap, are sufficient protection against any greater loss than that which it would sustain even when covered. The period of charring a heap of 12 to 16 feet in diameter, and $2\frac{1}{2}$ to 3 in height, extends over two or three days before the work is finished. The modification of the process, by the construction of a chimney in the middle of the meiler, so that it may serve as a draught to any portion of the mass, has been productive of great advantages in coke-making, and has, with slight modifications, been adopted in Staffordshire, on the Clyde in Scotland, and at several other places. This appendage to the "meiler" is usually of a conical form, the base being about 3 feet in diameter, and from $1\frac{1}{2}$ to 2 feet at the top. The bricks are laid so that intermediate channels present themselves all round the pile. At the top it is solid, and closed with a lid. Its height is usually 3 or 4 feet. Around the base of this chimney the coals are piled, employing the larger pieces for the base, and putting the smaller ones on towards the top and outer surface. Several channels are fashioned in the mass from the base of the chimney to the outside of the heap, through which a supply of air traverses to the region of combustion. The preliminaries being effected, and the heap coated with powdered coke or rubbish, fire is introduced at the mouth of the chimney, either by means of ignited coals or wood. The heat which is evolved laterally through the openings in the chimney very soon ignites the coal adjoining, and the heat extends gradually outwards to the circumference as the charring advances. As soon as the thick heavy smoke from the chimney is replaced by a lambent blue flame, it is significant that the fire has traversed the entire mass. It is now watched till the azure flame abates, at which time the draught of the chimney is cut off, by depressing the cover and filling any chinks or cracks in the coating with fresh material. After the lapse of a few days, the process is finished, and the coke is ready for drawing. Fig. 32 represents a vertical section of this mode of charring, showing the chimney and the draught holes opening in all its circumference, and thus offering a flue for the volatile products to pass away. Sometimes this kind of meiler is ignited at several parts at the outside, near the channel flues at the base. In a short time the fire will reach almost to the centre. A few air or vent holes may now be made in the covering, by thrusting an iron bar into the heap. The smoke and other volatile compounds issue partly by these, but care must be taken to frequently renew the perforations, as, when the coals are very bituminous, the fusion of the mass is apt to choke them up. In about twelve hours or less after ignition the fire will have spread over the whole heap, which may then be loosely covered with coke refuse and ashes, leaving the vent or chimney still free. During two or three days the smouldering proceeds, by which the volatile portions suffer distillation, and are emitted by the orifice last mentioned, and the cooling will have advanced so far as to allow of the coke being used. By this mode of permitting the whole heap to get ignited before covering, and subsequently leaving the chimney open, the elevated temperature is retained sufficiently to carbonize the mass, and at the same time a waste of coke is avoided; moreover, another important advantage is gained in the expulsion of much more sulphur than could be effected if the air were more freely admitted during the operation.

Fig. 32.



It deserves also to be mentioned, that the coke manufacturer, by constructing the meiler upon a moist ground, effects a purification from the sulphur by means of the vapours arising from the soil and passing through the red-hot mass. In this case the water must suffer decomposition, its oxygen passing over to the sulphur, so as to form sulphurous acid, and the hydrogen constituting, with the carbon, light hydrocarbons, thus.—

$$2H_2O + S + C = SO_2 + CH_4.$$

When the sulphur is united to a metal, and the aqueous vapour transmitted over it, the following changes are more prevalent, assuming M to represent the metal in combination:—

$$H_2O + MS = MO + H_2S.$$

If, however, the heat be too great, or more air than is requisite be permitted to pass through the mass, this decomposition will not take place, and the sulphur in great part remains. The same end might be obtained by suffusing the ground with water before forming the heap.

It should be remembered, however, that in this case, as in the charring of wood, in proportion as watery vapour traverses the incandescent mass, so a loss of the carbonaceous substance is sustained. This will be evident from the above formulæ; but the importance of having the sulphur removed from the coke, especially when destined to be used in the smelting of iron, is much more thought of than the advantage of obtaining a large product.

For the most part it happens that the circular mound, notwithstanding the assistance which the central chimney affords, is too massive and solid to allow the heat to operate with its fullest effect upon the coals. The want of this distribution of heat is supposed to be the cause of the coke retaining more or less hydrogen and oxygen, which injure in some degree its value. To remedy this, the method of *coking in rows* is resorted to. A site is marked out, the extent of which depends upon the amount of coke which is to be prepared. A line is stretched along the length of the plane, in the middle of the space which the ridge is to occupy. At the distance of 7 or 8 feet apart, stakes, 6 to 8 inches in diameter, are fixed in the ground. Large pieces of coal are then laid at each side of the string, and inclined to one another, so as to leave a channel in the midst. To insure greater strength to the walls, if the first rows may be so termed, the plane of cleavage of the coal should form a right angle with the length of the heap. Other layers of coal in proportion to the size are placed beside and upon the first two, using the largest coal first, till the row is sufficiently high and wide, taking care that air channels are left at intervals in the base. The usual height to which these ridges are raised is about 3 feet. When completed, the whole is covered with coal dust or cinders, and fire applied at several parts adjoining the air channels; the stakes are likewise drawn, and live coals thrown into the vacant space which they leave. In a short time the whole mass will be in a state of active combustion. As soon as the heat has penetrated to the centre, the pile may be covered more closely, leaving the portion left void by the stakes as free as possible, so as to perform the office of a chimney. In case these should get choked by the fusion of the coal, they must from time to time be cleared by thrusting a bar of iron into them, or into any parts where the combustion is dilatory. As soon as the white flame disappears, and is succeeded by a lambent bluish blaze, all the orifices are closely covered, and the whole is left to cool.

Such is the simple mode of coking in heaps and rows, but it may be remarked that particular modifications are required according to the kind of coal which is to be carbonized. Thus, when there is a large portion of fusible matter in the coal, care must be taken that the draught holes or flues are sufficiently wide to admit of the increased volume which it acquires by the effects of the heat upon it, without being closed thereby; the fire also must be allowed to spread over the whole heap, as well interiorly as exteriorly, before it is partially covered with the refuse matter. When, by a closing of the draught or flue holes, air is prevented from entering to the heart of the mass, considerable time may elapse, and much of the exterior may be consumed, before the interior portions are charred; and it not unfrequently happens that while the outside of a ridge is completely coked, the interior is left intact. As an auxiliary to the process, when very bituminous coals are operated upon, the fire should not be kindled in the chimneys or spaces left by the stakes till the base be well ignited; the facility which these afford for the escape of the products of combustion will expedite the process, and the result will be the general charring of the heap, whereas, if these precautions were not taken, the work would be but partially performed. The same observations will apply when the coal is small, and, therefore, forms a ridge which is less impervious to air. In the latter case, instead of stakes being driven into the centre, brick chimneys are erected, as in the meiler system.

Where there is a great demand for coke, and the area admits of the construction of a large heap, one portion may be undergoing carbonization whilst the other is being constructed, and thus the process of coking may be rendered continuous. The method of charring in ridges is preferred in most establishments where furnaces are not erected, as it affords a better coke, and is more expeditious than the other method. Among the more recognized benefits are the partial purification from sulphur, which arises, as has been stated, from the fact that the steam which evaporates from the base of the heap passes over the coke whilst at a red heat, and operates as already mentioned; hence, to insure this, it is customary, wherever practicable, to cut a dyke around the carbonizing plot, the water from which keeps the ground always damp. Besides the advantages which accrue from the floor of the heap being moist, the water is always required to arrest the too rapid combustion which is apt to take place in some parts of the ridge, and also to extinguish the incandescent charcoal when it cannot be allowed to cool spontaneously.

Another system to which the coke manufacturer has recourse is that of heating in ovens. In this case the heat employed for effecting the carbonization is generally within the oven or furnace, and at the expense of a portion of the fuel. Were this not so the product would be wanting in the necessary density and compactness for the iron furnaces, and, like the coke from the gas works, would not be adapted for generating high degrees of temperature. The method of coking in ovens is practised also for economy, as not only yielding a larger product of coke, but affording the means of recovering some of the products of the distillation. It is not, indeed, without its inconveniences, more especially if the coals be very much charged with sulphur; for in this case the coke retains that injurious element in much larger quantities than if the carbonization were effected in the open meiler. The ovens, however, can hardly be excelled for the production of a hard dense coke; and hence they are employed by several iron smelters.

The commoner arrangement for the coking of coals in this manner is seen in the annexed engravings (Figs. 33 and 34), the first of which shows an elevation, partly in section, of a series of four ovens constructed in a line for the purpose of economizing

Fig. 33.

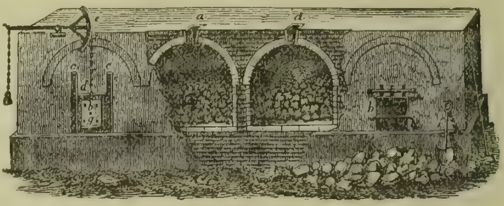
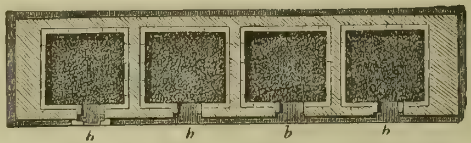


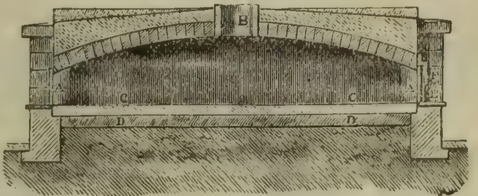
Fig. 34.



the heat; and the other a plan. They have a square or oblong form, with an area of 12 feet by 10, or less, according to circumstances. The height of the furnace is also variable, differing from 3 to 10 feet. Sometimes about 1200 cubic feet of coal are charred in each at once. The walls of this construction, including the fireproof facing, are about 2 feet thick. In the arch is an opening, *a*, 2 feet in diameter, through which the gases and other products of combustion pass off. No grating is supplied in this case, the air being admitted through a perforated door, *b b b*, about 3 feet square, in the front near the base. This door is sometimes constructed of a stout perforated cast-iron plate; sometimes it consists of a mere frame, *d*, within which bricks are laid at such distances as will leave sufficient space for the admission of air. It is movable in grooves, *c c*, by means of a main, *e*, attached to a counterpoised lever. The coals are introduced through this, as well as by the superior orifice; but it is stated that, when the charge is supplied from the top, the coke is not so good as when it is deposited in the furnace through the front door. It appears difficult to assign any cause for this, other than that, when the filling takes place from above, the central part becomes so compact as to obstruct the free passage of air through it. Before charging, if the interior be not sufficiently hot, some wood is ignited inside the front door and allowed to burn. During the evolution of dense volumes of smoke the front door is left open, and also the apertures in the door at the base; as soon as these disappear, however, both are closed, and the contents are allowed to cool. After twelve hours, or longer according to circumstances, the solid mass of coke is broken, drawn out with rakes, and wheeled off in iron barrows to a receptacle where it is cooled by sprinkling it with water. After a furnace is lighted, the first and second batch of coke which it yields is very much inferior to what is produced when it has been in operation regularly for some time; this arises from the circumstance of the base and appendages not being sufficiently heated. After a few charges have been carbonized, and the masonry has become heated, the coke has not the sponginess which characterizes the first charges; the time occupied is also shorter, and there is no occasion for adding any fire, as the heat of the base and side walls is sufficient to ignite the coal in contact with them.

In the vicinity of St. Etienne, and other localities in France, a coke oven is in use similar to what is represented by Fig. 35 annexed. In appearance it resembles an ordinary baker's oven, with a low arched roof, and a flat hearth without a grate. The bed, C C, of the oven, which is nearly 12 feet wide and 23 feet in length, is composed of a layer of refractory clay, well beaten down, and resting upon a base of cinders or other rubbish, D D, rendered as compact as possible. At each end of this oven there is a working door, A A, 2 feet 9 inches in width and 2 feet in height, surrounded with a framework of cast iron fixed in the wall, and in which a small sliding-door, E, moves; there are likewise apertures, F, for affording a view into the interior of the oven; and in the centre of the arch a space, B, about 18 inches in diameter, is left to serve for a chimney. The height of the oven, from the hearth to the most elevated portion of the arch, is 4 feet. Above the arch, which, like the hearth, should be composed of refractory material, common stone, mixed with sand and mortar, serves to give the whole solidity, and to retain the heat. The charge is lighted by first heating the interior with wood, but after a few charges have been drawn, the walls and hearth are sufficiently hot to cause the combustion of the coal. The depth of coal spread upon the hearth should not exceed 8 inches if it be of a caking nature; but when it has little of this property the layer may be 10 inches. A little water is sprinkled on the mass to promote its caking, and the whole is rendered as compact as possible. As soon as the layer is uniformly spread, the doors are drawn down nearly to the bottom, leaving a few inches free, however, for the admission of air. At first aqueous vapour is given off, followed by sulphurous acid and the other products of combustion; but it is found advisable to suppress the rapid evolution of the latter, and to allow the slow expulsion of all moisture, at such a temperature as will be conducive, in the presence of steam, to depurate the coke from sulphur. All these products pass off by the chimney in the roof. When the whole of the moisture has been expelled, the disengagement of the combustible gases becomes more voluminous, and the gases themselves more inflammable; they ignite, and a smoke of a black colour succeeds the dense yellow cloud which was given off during the emission of the watery vapours in conjunction with other bodies. When the black smoke appears the draught is increased by raising the door to the height of 3 inches, in order to expel the whole of the volatile products. By this means the mass is in a short time raised to a cherry-red heat. After the lapse of from half an hour to an hour, the fuliginous cloud vanishes, and the gases emitted appear whitish. At this stage the heat will have spread over the whole mass, and a contraction in the bulk will have taken place, as may be judged from the appearance of numerous cracks and fissures in the red-hot mass. In about three-quarters of an hour these crevices will have penetrated to the hearth, and the entire contents will be at a full red heat. The doors are now tightly closed, as well as all the other apertures through which air might enter, and the contents of the furnace left to complete the carbonization. It is necessary to watch the opera-

Fig. 35.



tion, lest by the admission of the air through the chimney, which is the only opening left, a loss of coke might occur. After the doors are closed the flame and smoke still pass off, but the latter by degrees becomes more attenuated and whiter, till it nearly ceases altogether; and as the pressure in the chimney is at this period considerably reduced, there is evident danger of a double current being established in it; namely, an outward current of the products of combustion, and an inward one of air. To guard against this, the mouth of the chimney is gradually contracted as the pressure of gases from within becomes less, till at their disappearance it is entirely closed. Attention must now be given to withdraw the coke in such a manner as to retain as much heat in the furnace as possible. To effect this the doors are thrown open, and the mass of coke quickly broken up with long staves, then raked out, and conveyed away in barrows to a receptacle where it is sprinkled with water whilst red hot, both for the purpose of extinguishing the combustion and removing any excess of sulphur. Another charge is introduced as rapidly as possible, and after the preliminary operations already pointed out have been gone through, the doors are closed, and the charring is again managed in the same manner. Each charge is worked off in about twenty-four hours.

Pernolet's Coke Oven.—The following description is abstracted from a paper read by M. Pernolet before the Institution of Civil Engineers, vol. xxiii., from the Proceedings of which the accompanying figures are taken.

"In the improved system, the method of charring is founded principally on the theory of keeping the coal from all contact with the atmosphere during its distillation, of performing that process very slowly, and of collecting and turning to account all its products, while the coke shall retain all the solidity, lustre, and density which are its distinguishing characteristics, when manufactured in the best manner by the ordinary means.

"Before entering into a detailed description of the apparatus, and in order that a just estimate may be formed of the reduction in the price of coke which must result from its employment, it will be necessary to state that the supplementary products due to the improved arrangements are, a larger yield of coke, and all the tar, the ammoniacal liquors, and the gas, which would be obtained from the same coals if distilled in the retorts of a gas manufactory.

"The increase in the yield of coke depends partly on the kind of coal, and partly on the way in which the charring was done before the introduction of the improvements. In the great coke works at St. Etienne, where ovens with hemispherically vaulted tops are used, the yield of coke has been advanced from 58·8 per cent. to 69·3 per cent., and in the 'Fonderies et Forges d'Alais' from 54·6 per cent. to 69·5 per cent. In general it may be said that the increase in the yield, from the rich and partially rich coals, is from 10 per cent. to 15 per cent. Consequently, in distilling the same quantity of these coals, there will be a return of coke exceeding by one-sixth, on an average, that which was obtained from the old ovens before their alteration. As to the tar, the proportion collected depends on the nature of the coal, and on the care taken both in the distillation of the coal and in the condensation of its volatile products. This proportion has averaged upwards of 2·53 per cent. at the 'Forges d'Alais,' 3 per cent. at Elonges, 3·25 per cent. at St. Etienne, and has reached as high as 5 per cent. from the ovens of the Paris Gas Lighting Company, where only very bituminous coals are employed. Taking, therefore, the average of these manufactories, the amount of tar obtained from the bulk of coal distilled may be reckoned at 3 per cent. The proportion of ammoniacal liquors depends not only on the conditions mentioned for the coke and tar, but also on the quantity of moisture contained in the coal. At the works of the Paris Gas Lighting Company, where unwashed coal is used, for every 100 parts of coal distilled, there is not obtained much more than 6 parts of ammoniacal liquors; while at Elonges, at Produits, and at St. Etienne, where the distillation is principally from washed coal, the quantity of liquor collected amounts to 10 per cent. or 12 per cent. But in other respects the useful substances contained do not appear to have any relation to the amount of water collected; and the aggregate of resulting ammoniacal substances shows but little variation for the different coals which have hitherto been tried. Provided the condensation be properly attended to, this quantity may be stated at a weight of not less than 10 lbs., and sometimes of as much as 13 lbs., of sulphate of ammonia per ton of coal distilled.

"Where coke is manufactured for metallurgical purposes, as at Elonges, at Produits, at St. Etienne, and at Alais, it is not usual to collect the gas given off, but it is conducted beneath the ovens, to be there consumed in maintaining the necessary temperature for distillation. Provided that the coal is rich, as at St. Etienne, or partially rich, as at Alais, this gas will be found sufficient for the purpose (precaution being taken to avoid the risk of explosion); but generally it is desirable to force the heat, in order to obtain at once a firmer coke and a tar richer in benzine. This is effected without any increased expense by burning in addition, in the fire-grate, either the small rubbish which is not good enough to be sold as coke (and which at St. Etienne forms from 2½ per cent. to 3 per cent. of the weight of coal distilled), or the residue from the washing, which is of equally small value, and amounts at Produits to about 10 per cent. of the volume of coal distilled.

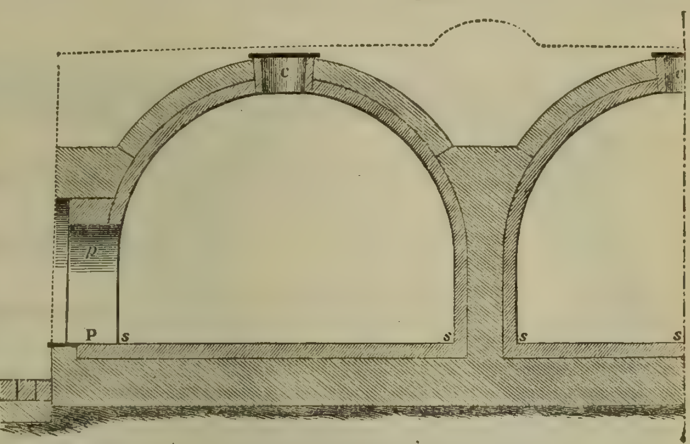
"It follows, that by the improvements in the manufacture of coke, there can be extracted from 1000 tons of pit coal:—1st, from 650 tons to 700 tons of good coke, instead of the 500 tons or 600 tons generally obtained in England; 2nd, from 25 tons to 40 tons of tar; 3rd, compounds of ammonia, equivalent to at least 5 tons of sulphate of ammonia.

"This reduction might be carried still further if all the gas, or even part of it, were made use of, as there is every facility for doing, particularly in those metal works which have both coke ovens and gas apparatus, and also in those small gas factories where cannel coal is generally used.

"In the foregoing remarks the employment of the richer, more bituminous sorts of coal has been implied, and these are, in fact, the best adapted for obtaining the products of distillation. But, though the saving would not be so considerable, the improved ovens may be profitably used for the poorer coals, and even for the anthracites, provided that some of the richer kinds be used with them, as is done at the 'Forges du Creuzot.' In such cases the economy would consist chiefly in the smaller quantity of the superior coal required, but of course the products would be proportionately less abundant, in consequence of the small amount of tar, hydrate of ammonia, or gas furnished by the poorer part of the mixture.

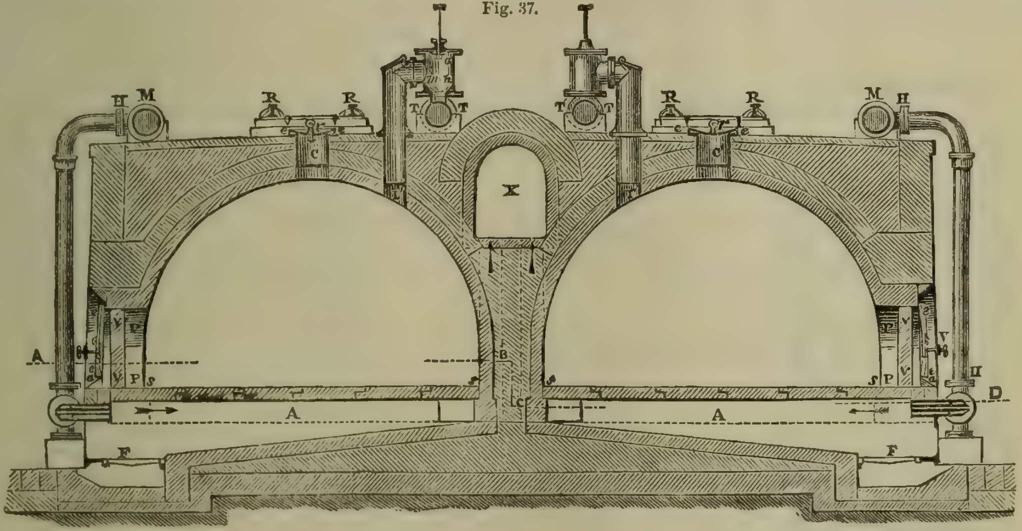
"The alterations on the ordinary coke-oven consist:—1st. In raising the floor about a foot, and so arranging it that it can be heated from below by means of a fire-grate and flues; 2nd. In making a new opening in the roof, in which is fixed a pipe for the reception and conveyance of the volatile products; 3rd. In so arranging the openings of the old ovens that they can, by means of movable plates of metal and clay, be hermetically closed during the distillation; and 4th. In the addition of a chimney to the masonry, for the purpose of securing the circulation of the products.

Fig. 36.



"In Fig. 36 the coke oven most in use in England is shown unaltered; and in Figs. 37 and 38 the same oven is represented as altered with the above improvements. *s s s s* is the floor, raised about a foot; underneath it is the fire-grate F, provided with flues A A and A″. I is the opening in the roof. T is the pipe intended to receive the volatile products. P and C are the two usual openings. Fig. 37 shows the same openings, with the addition of the movable plates.

Fig. 37.



"Figs. 37 and 39 show the chimney added to the masonry, X and Y. The dimensions of this chimney, as ascertained by experience, should be 50 feet in height, and the inside area should be not less than 3½ feet square, for a group of sixteen ovens. The sectional area of the main flue should not be less than three-fourths of that of the chimney. The oven is represented as arranged for being charged from above, by means of wagons running upon rails, R R, Fig. 37. This plan is the most convenient and the most expeditious. The wagons are brought up in succession over the opening C, and are then emptied into a movable iron funnel, which must be large enough to receive the whole charge at once; and as the coal falls on the floor, a workman, stationed at P, spreads it equally. In this way a charge of more than 5 tons can be introduced in fifteen minutes or twenty minutes, a most desirable rapidity to preserve the heat of the oven when the charge is being renewed. Should it, however, not be deemed advisable to arrange the ovens for receiving the coal in this manner, the coal may be conveyed through the door, P, in the way most usual in England; but the latter mode is not only slower, but more fatiguing to the workman, on account of the greater height of the floor.

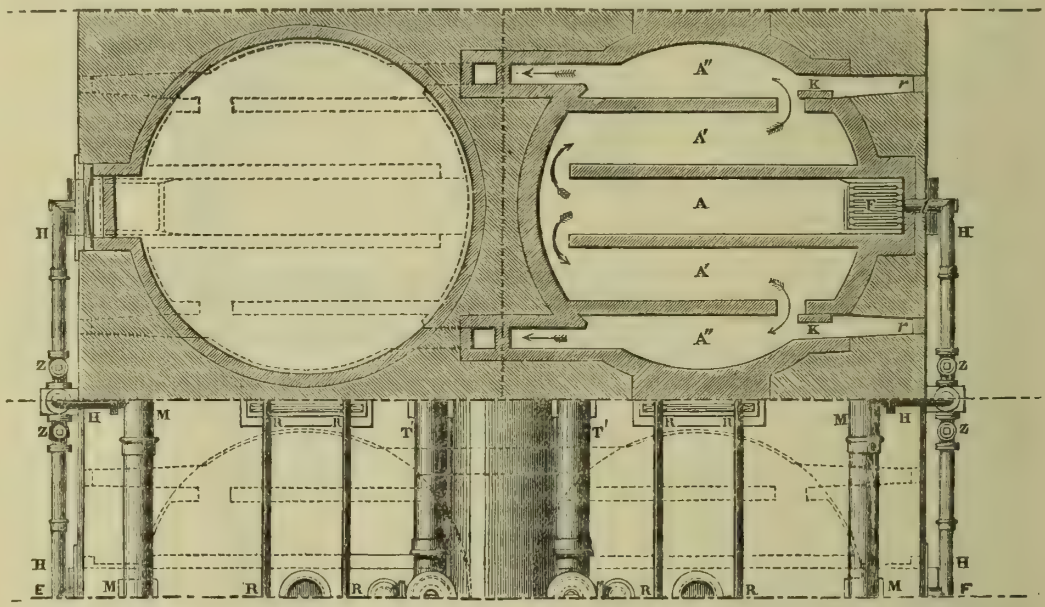


Fig. 38. (Section along A B C D, Fig. 37.)

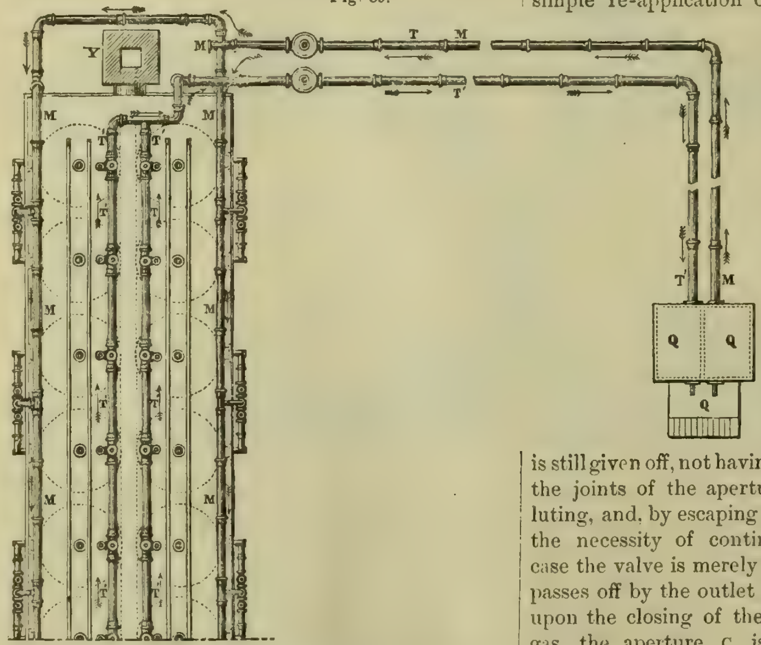


Fig 39.

"When the charge has been equally distributed, the door is closed, fastened with a screw, and closely luted with loam; and until the coking is nearly completed no further attention is required, beyond seeing that the joints allow neither the air to enter nor the gas to escape, and that the heat is sufficient, and is equally distributed over every part of the floor. The first of these objects is effected by the simple re-application of loam wherever there are signs of its being wanted; the second, by the maintenance of a due supply of gas to the fire, through the blast pipe, and by a free draught of air through the centre pipe, or round the edge of the blast pipe, and by a proper distribution of the flames in the flues.

"To try whether the distillation is finished, the valve *o*, Fig. 37, is closed; the communication between the pipes T and T′ being thus intercepted, if the charring is incomplete, the gas which is still given off, not having the means of escape, strains the joints of the apertures, cracks the surrounding luting, and, by escaping in the form of smoke, proves the necessity of continuing the process. In this case the valve is merely re-opened, and the gas again passes off by the outlet pipe. If, on the other hand, upon the closing of the valve there is no escape of gas, the aperture, C, is opened, and a temporary fire-brick wall, separating the charge from the door of the oven, is taken down. It is important not to open the door before cutting off the communication between the pipes T and T′, otherwise the external air would get into the pipe T′, and become mixed with the gases which are circulating there as they proceed from the other ovens. This arrangement is more fully shown at T′ T′ T′ T′, Fig. 39. The door once open, the coke is removed with a rake or shovel in the ordinary manner. While this is being done, the cast-iron cover at C′ is kept shut, to avoid the risk of igniting the coke, by the draft of air which it would create if open.

"When the charge has been completely withdrawn, and the cover opened, the oven is recharged. Both at this time, and while the coke is being withdrawn, the gas brought from the other ovens, by the great common flue, and collected by the small common flue, M M M, Figs. 37, 38, and 39, is allowed to pass continually into the fire-place; so that the floor is kept hot, and the gas begins to show itself above the opening only a few minutes after the closing of the door. The covering is immediately put on and luted, and the communication is re-opened between the interior of the oven and the great common flue, by raising the valve.

"Should it appear that one side of the oven is insufficiently heated and the other too much, the registers, K K, must be advanced or withdrawn by means of a hook; or if the supply of gas is too small, the cock, Z, Fig. 38, must be opened rather more.

The products of the distillation are drawn off by the draught of the chimney, together with the condensation of the liquid, and the cooling of the gaseous products tends to create a vacuum, which assists the current in the direction shown by the arrows, Fig. 39. The products circulate thus in the great general flue, penetrate into the condensing apparatus, Q, Q, Q, Fig. 39 (where they deposit most of the tar and ammoniacal liquor), and return to the ovens by the small general flue, whence the gas, purified and dried, passes to each fire by the pipe, H H, Figs. 37 and 38.

"The chief uses of the fire-grate are to heat the ovens, when they are set to work afresh, and to raise the temperature of an oven which is not so hot as the others. In this case, the small, unmarketable coke, unavoidably made with the larger, is found to be a sufficiently good fuel. Lastly, in the event of part or the whole of the gas being utilized elsewhere, the fire-grate will be indispensable, for receiving whatever fuel is to be burnt as a substitute.

"The products of the distillation pass through the passages marked by the arrows, and rise to the gallery, whence they escape into the atmosphere. The time occupied in charring varies with the arrangement of the oven, the nature of the coal, and the density desired for the coke. At St. Etienne it is upwards of seventy-two hours for rich coal, but the ovens there used differ from that which has just been described, the form of the vaulting being more elliptical. At the foundry of Torteron, where the rather poor but very flaring coals of Commentry are used, and where the system of the 'Société de Carbonization' has been applied to the Belgian ovens, the time occupied is only twenty-four hours."

With regard to the working of this oven, a paper was read by A. L. STEAVENSON on the 5th October, 1872, and is published in the "Transactions of the North of England Institute of Mining and Mechanical Engineers," vol. XXV., from which it appears that it has been tested in this country both by Messrs. BELL Brothers and by the Wigan Iron and Coal Co. on a large scale. The results of a large experience gave—

	Coke.
For 100 tons of coal distilled, ...	68·00
Tar, ...	2·4
Ammoniacal water, ...	5·2
	75·6

or, say, in round numbers, 76 per cent.

In addition to this there was the refuse coke or "black ends," which, as mentioned before, were burnt upon the grates below the floors, and amounted to about 3½ per cent.; and the writer is warranted in assuming that, from inability to connect the oven with the condensers when first started, until the air and moisture were expelled, there were other losses amounting to 2½ per cent.; and the results accounted for thus reached in the shape of coke, tar, and ammoniacal water, a total of 82 per cent., the remainder, or 18 per cent., being gas, which was burnt beneath the floors of the ovens, but never exactly measured. The ammoniacal water was treated as usual, and sulphate of ammonia manufactured during many months. One period of five months (selected merely because some special statistics were available) produced 14 tons of sulphate, which was afforded by 70,676 gallons of ammoniacal water; this is a yield in sulphate of ammonia of 4·5 per cent. of water treated. The quantity of coal used during this period was 7591 tons, so that a result was obtained of only 4·15 tons of ammoniacal water, and ·185 ton of the sulphate per 100 tons of coals. A good deal depends upon the time which can be spared to allow of separation in the tanks, which process should, if possible, extend over seven or eight days. Summarizing these results, there is obtained from each 100 tons of coal treated—

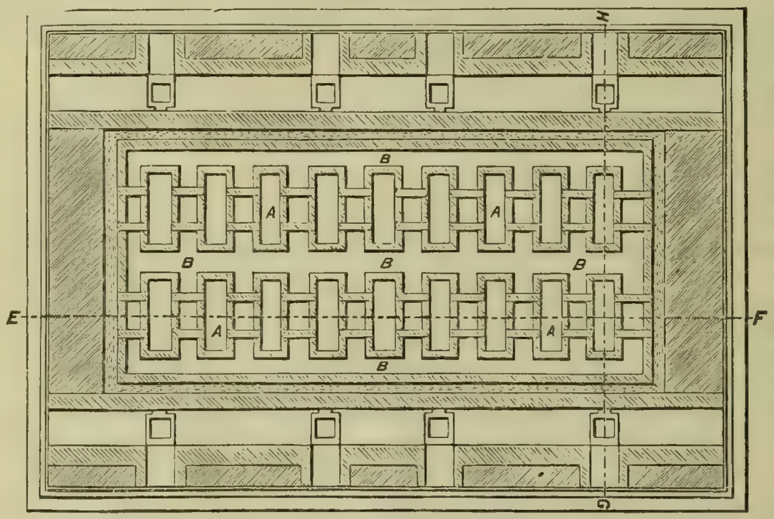
Coke, ...	68·00	per cent.
Tar (supposed anhydrous), ...	2·40	"
Sulphate of ammonia, ...	·185	"

These results might be slightly improved by having reservoirs to allow the liquids to rest a week; and the production of ammonia might be more favoured by cooling the condensers, and by introducing a shower of ammonia or fresh water for it to saturate, as no doubt the gas returned to the fires still contained a considerable proportion of it; or the gas might have been passed through a bath of sulphuric acid and water. By these means the tar might have been increased to about 3 per cent., and the sulphate of ammonia to, perhaps, ·3 per cent.

The author proceeds to account for the system not being successful, because the resulting coke was soft, and showed a large number of "black ends;" that each oven was under repair for six weeks in the year; and that "the alternative was either to make a good or fair coke, and burn the oven down in a very short time, or save the oven and make soft coke."

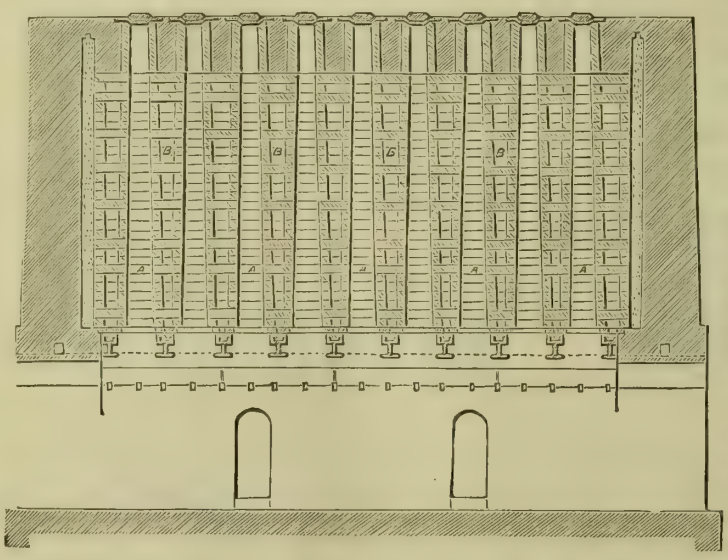
On the other hand, the statements made on the Continent of the successful application of the Pernolet oven are very decided.

Fig. 40.



Appolt Coke Oven.—The following description of the Appolt oven is from a paper by MM. Appolt in the "Annales des Mines," 1858. The drawings, Figs. 40, 41, 42, are those given by Steavenson. Fig. 40 is a plan; Figs. 41 and 42 are vertical sections along the lines E F and G H, Fig. 40.

Fig. 41.



The oven consists of a series of upright retorts, A, of rectangular section, the larger side being two to three times the other, which are slightly wider below than above. Each of these has its own walls, and is surrounded on all sides by air-spaces, B, as shown, these spaces being all in communication; and the walls which form their sides are connected together by solid blocks of fire-brick. The whole is contained within solid vertical walls of fire-brick, between which and the external walls of brickwork is a space which is filled either with sand or some other non-conductor of heat, and which also allows for any slight dilatation of the brick-work.

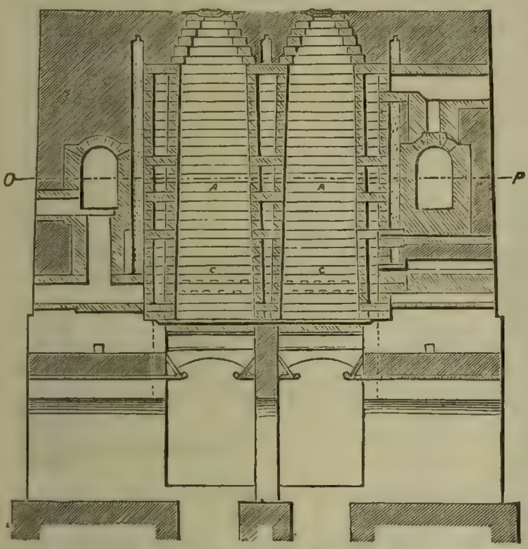
The retorts are filled by shooting coal in above through the openings shown, which are formed by carrying up the broader sides in a series of steps, and the narrow sides vertically. The object of giving a pyramidal form to the retorts is to assist in drawing, the load of coke falling out of itself. The bottom consists of cast-iron doors, falling down when required, which deliver the charge into iron wagons below. The doors are strengthened by cross bars of wrought iron. In the sides of the walls below the openings there are fixed inclined and projecting pieces of cast iron, so as to prevent the coke from falling with too much force into the wagons.

The partition walls of each chamber are traversed near the foot by two rows of small openings, C, Fig. 42, through which the volatile products pass, to be consumed in the surrounding spaces by means of the air which is admitted through flues in the wide sides of the ovens. Other similar small holes, not shown in the drawing, are employed in the upper portion of the retort when caking coals are employed. The products of combustion are carried off to the chimney by means of flues, which have dampers of fire-brick for regulating the draught, and in which there are openings to allow of their being cleaned out.

In order to dry the ovens throughout, a moderate fire is made in each of the retorts, and is kept up by the supply of coal from above until the sides of the retort are red-hot, when the top is closed, and by opening the dampers of the air-flues, part of the products of combustion dry the outer walls. As soon as the whole is perfectly dry, which operation requires a week to ten days, the charge of coal is introduced and the top is placed and luted on with clay.

The gases from the coal, which are evolved by the red-hot sides of the retort, pass into the surrounding spaces, where they mix with the air introduced, and their combustion sustains the temperature. An hour afterwards another is filled, and so on until all are charged. As the quantity of gas increases or decreases, the dampers have to be opened or shut. The coking only requires twenty-four hours, so that the charge is drawn on the second day at the same hour as the charge was made the previous day, and the charge is again made as soon as the former one is drawn, so that the process is continuous.

Fig. 42.

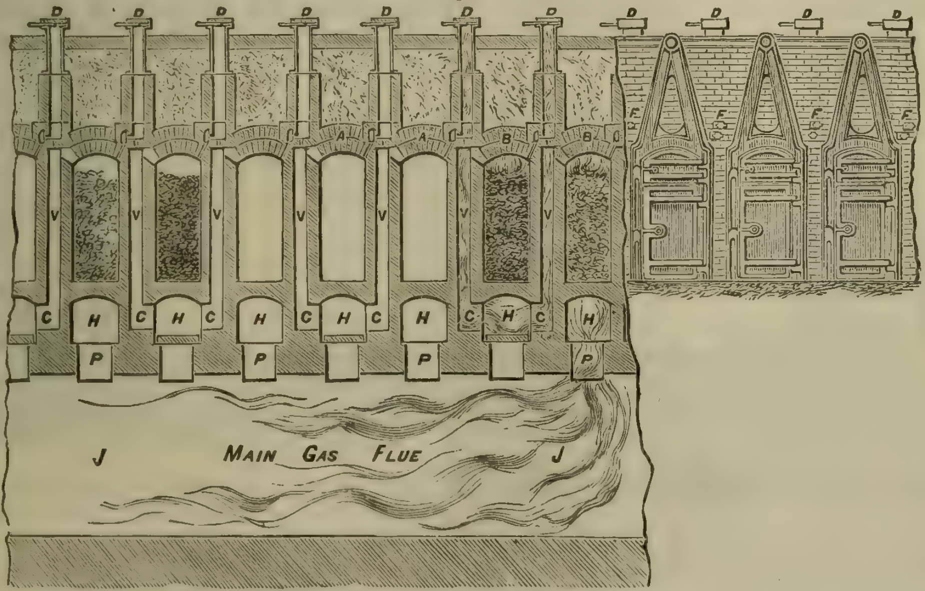


The principle of the process is that of a retort, as the compartments are closed, except at the apertures where the gases escape. There is a large amount of heating surface produced by the way in which the retorts are built in blocks; and owing to their small width the carbonization takes place very quickly, and there is also a thorough mixture of the gas and air, producing perfect combustion in the spaces; the temperature of the oven is always constant, as the charging of the retorts takes place in regular order. It is also stated that its relative power of production is greater than that of other ovens.

From the considerable experience that has been had of this oven, it is found that a charge can be completely carbonized in twenty-four hours, and this regular action allows of the uniformity of temperature already mentioned. It has been further found that only day work is required both for charging and discharging, the ovens being backed up during the night. The average return of coke has been found to be between 70 and 80 per cent. with caking coals; very good results are also obtained with a mixture of caking and non-caking coals. The coke has been found to be of uniformly good quality, hard, and of great density. The gas produced has been found to be more than sufficient for carbonizing the coal, and the surplus has been used for other purposes, such as raising steam, &c.

Experiments have been made on this furnace by the inventors, as to the manner in which carbonization took place. Four hours after a compartment had been charged it was found, on opening the lower door, that the coal fell out in the same state in which it was put in, and that the heat had been employed in forming a layer of coke attached to the sides, of about 4 inches thick. The thickness of coke was found not to vary directly with the length of time the heat had been acting, and the reason given was that the coke, as a bad conductor, resisted the action of the heat to traverse it. These experiments have resulted in the exact form and the

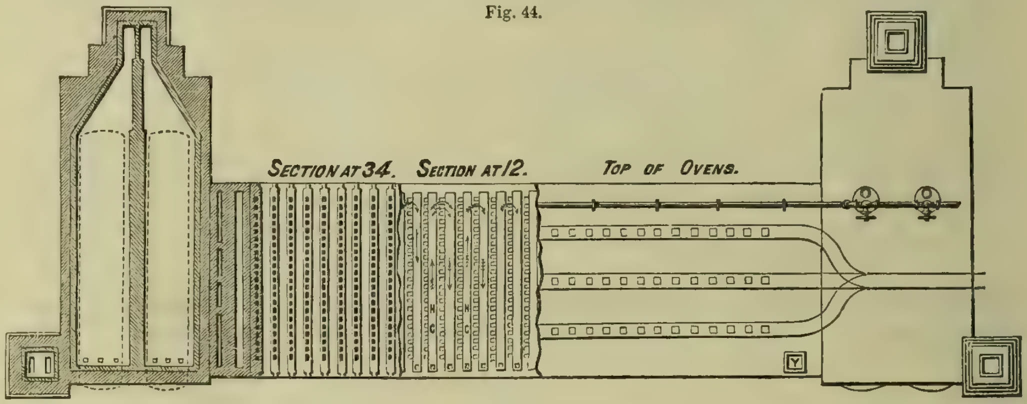
Fig. 43.



dimensions that have been given to the retorts, and also to the treatment of the coal previous to mixing. Percy says, in reference to this oven, that of all ovens known to him those on the Appolt system appear the most favourable for the production of a coke for metallurgical purposes; but he adds as a rider that "Menelaus has, however, informed the author (June, 1873) that some years ago he saw the Appolt ovens at work near Saarbruck, and that the late M. de Wendel, to whom they belonged, and who was an excellent judge of coke ovens, did not, at least at the time of Menelaus' visit, see any great merit in Appolt's scheme."

Coppée's Coke Oven.—The following description of Coppée's coke oven, and the plates from which the accompanying drawings have been prepared, are taken from a paper by E. Bainbridge in the "Transactions of the North of England Institute of Mining and Mechanical Engineers," vol. xxii.

Fig. 44.

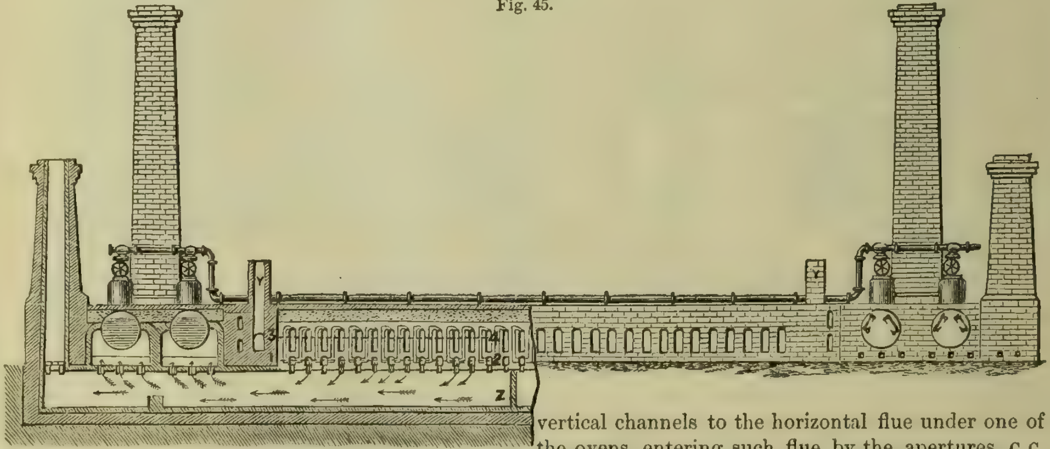


The general design of the ovens will be understood on reference to the accompanying drawings. Fig. 43 represents a section of several of the Coppée ovens. Fig. 44 is a ground plan of a complete stack of thirty ovens, showing the arrangement of flues and the manner in which the gases are carried beneath the boilers. Fig. 45 is a side view, partly in section and partly in elevation.

The ovens are of rectangular section, the usual dimensions being: length, 29 feet 6 inches; breadth, 18 inches; and height, 4 feet; and are charged every twenty-four hours. Others arranged to be charged every forty-eight hours are 5 feet 7 inches high, and 2 feet broad. The thickness of the brickwork between the ovens is 13·2 inches.

The coals, whether washed or otherwise, are crushed or disintegrated before being placed in the oven, to the consistency of very coarse meal. At each end of the oven are two metal doors moving on hinges, and fixed securely in metal frames, the lower door being 3 feet and the upper 1 foot in height.

Fig. 45.



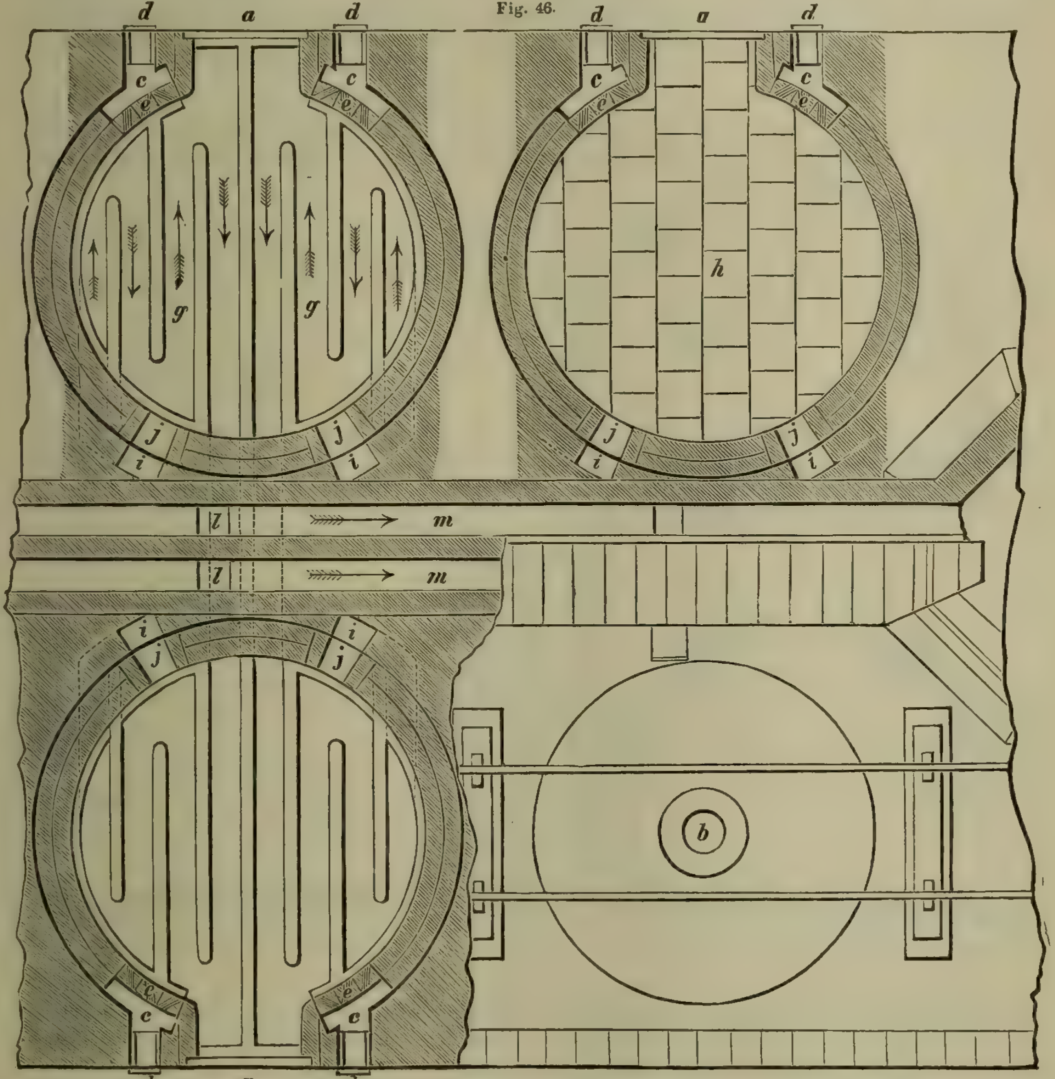
Between each two ovens are twenty-eight vertical channels, v v, which, leading from one side of each oven, convey the gases down to the horizontal flues, h h, one of which runs under each oven. The ovens are arranged in groups of two. The gases from each two ovens (a a or b b) take their course down the vertical channels to the horizontal flue under one of the ovens, entering such flue by the apertures, c c. The combined gases, after passing along this flue to the end of the oven, return by the flue under the other oven and enter, at the point p, into a large channel j, running at right angles to the ovens; air is supplied through the sliding doors, d d, f f. They pass from this channel, either direct into a chimney, or are carried under one or several boilers.

The coke is removed from the oven by means of a ram, propelled by a cogged driving wheel, which is worked by a small portable engine.

When the coke is ready to be taken from the oven, the engine and ram are placed opposite the end of the oven, and three wagons of coal are placed over the three openings at the top. The coke is then pushed out by the ram, the operation occupying about two minutes. The lower doors are then closed and the coal dropped into the oven, the apertures through which the coal passes being immediately covered up by sliding doors. The coal is levelled in the ovens by means of rakes passed through the opening of the upper doors, which are then closed. The whole time, from opening to closing the doors, is eight minutes.

This oven is only designed for disintegrated coal, the chief advantages claimed being rapidity of coking and an increased yield of denser and harder coke. The method of working the ovens in pairs, already described, namely, the charging one of a pair when the other is half coked, is to produce a mixture of the denser hydrocarbons evolved at a low temperature at the commencement of the operation with the heated gaseous products of the other, thus producing an intimate mixture and more perfect combustion.

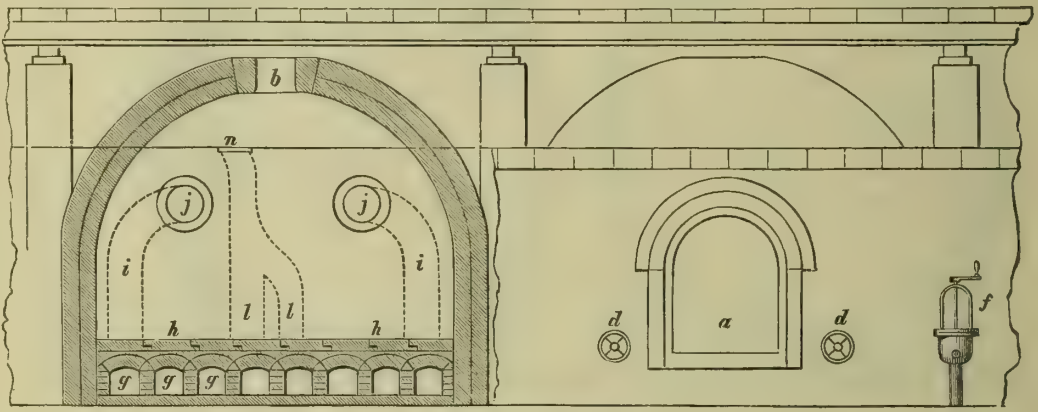
Fig. 46.



Breckon and Dixon's Coke Oven.—The following is a description of Breckon and Dixon's coke oven, the drawings being taken from the "Transactions of the North of England Institute of Mining and Mechanical Engineers," and representing a plan, Fig. 46, and sectional elevations, Figs. 47, 48. The feature of the invention, which was patented in 1860, is the construction of flues below the floors of the ovens, through which the gaseous products of combustion pass off to the chimney. In this way the floor of the oven becomes heated, and according to the trials extending over some years this results in the coking of the coal in two-thirds of the time required in ordinary coke ovens, and it appears also to have resulted in an increased yield of 20 per cent. It is also stated that the coke has been of better quality, being denser and stronger. *a* is the door, and *b* an opening above the oven, through either or both of which the coal may be charged; *c* is the pipe for air, admitted through a valve, *d*, to distributors, *e*; *f* is the hydrant. The improvement consists in employing flues, *g*, under the fire-brick floor, *h*, of the ovens, which itself rests on the side walls of the flues. The horizontal flues are in connection with vertical flues, *i*, and the openings, *j*, and with the chimney by *l* and *m*, in which are dampers, *n*, so that any oven may be cut off during repairs.

On lighting, the gases escape through the openings, *j*, down to the vertical flues, *i*, into the horizontal flues, where they circulate as shown by the arrows, and then pass away to the chimney. J. A. Phillips, in his "Elements of Metallurgy," states that it was found at one of the collieries in the neighbourhood of Darlington, after a trial extending over several years, that coal yielding 58 per cent. of coke in ordinary ovens, afforded 69 per cent. in those constructed with flues beneath the floor; also that a charge of 6 tons, which requires seventy-two hours for conversion into coke in the former, is in the latter completely coked in forty-eight hours.

Fig. 47.



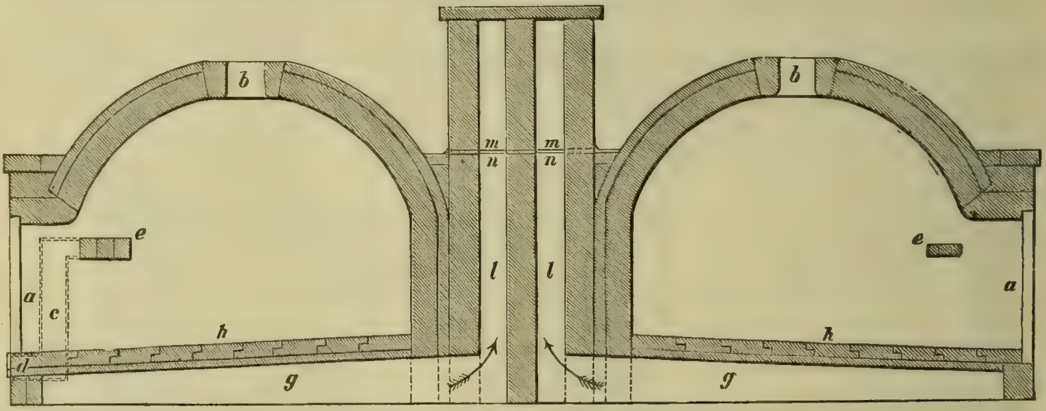


Fig. 48.

Such are the forms of furnaces adopted, and the processes usually followed in the manufacture of coke, but there are many modifications according to the nature of the coal. Some of these are calculated to afford a larger product, whilst others are intended to manufacture a purer coke than can be done by the ordinary method. The principle involved in those improvements which have in view the increase of the product, is such an equalizing of the temperature as to prevent the heat exercising an undue effect on one portion of coals, whilst another may not be fully charred. The advantage gained, however, even by the most careful management, does not, according to the researches of Karsten, amount, in the case of the charring of coals, to more than 5 or 6 per cent. Generally, the quantity of coke which a coal produces depends more upon its atomic constitution, and the amount of ash which it contains, than upon any other condition; and without these data, it is nearly impossible to judge what quantity of coke a coal will yield. The analytical tables given previously will throw some light upon the amount of product from many varieties. British coals usually average from 54¼ to about 73 per cent. American coals examined by Johnston yield about the same quantities. In either case the inorganic constituents, which take from the heating effect of the coke, are included in the calculated amount. By deducting the matters constituting the ash from the coke, and comparing the principal combustible with the content of the original coal, the numbers will stand in nearly the following centesimal proportion for the varieties mentioned:—

	Entire content of carbon in coal.	Pure coke produced therefrom.
Sand coal,	75 to 80	55 to 65
Sinter coal,	80 " 85	60 " 70
Caking coal,	85 " 90	60 " 80
Anthracite sinter coal, sand coal,	90 " 95	85 " 94

As already intimated, the quantity of carbon in the coal previous to charring is no certain guide to the estimation of the coke which it will produce; for some varieties very rich in this element, but associated with hydrogen and oxygen to a considerable extent, yield but a low percentage of fixed matter after the fire has exerted its influence upon the mass. To arrive at the knowledge of how much coke any particular kind of coal will afford, recourse must either be had to an accurate analysis of the substance, or a careful observation of the actual mean produce of a number of charges.

Desulphurization of Coke.—Nothing practical can be said to have been done in this matter, although various processes have been proposed having this object in view, as well as for the removal of the phosphorus and stones and ash. The methods which have had a certain amount of experimental application are the admixture of neutralizing agents to the coal, and the after treatment of the coke. It may be here stated that the extra cost in the production of the coke, which would result in the application of any of the methods hitherto proposed or patented, would be a serious drawback to their application, more particularly as the most satisfactory of the methods produces a maximum desulphurization of only 50 per cent.

It may be stated shortly that this subject has been most fully considered by PHILIPPART in the *Revue Universelle des Mines*, 1871, vol. xxviii., who has given a report on the subject in a prize essay published as above. First he treats of the removal of the sulphur as bisulphide of carbon during carbonization; then as hydrosulphuric acid, from a treatment with steam or hydrochloric acid; and again as sulphurous acid, by treatment with oxygen, either at atmospheric or increased pressure. In order to obtain a maximum of desulphurization he made a laboratory experiment on small pieces of coke, using nitric and then hydrochloric acids, with the following results:—

	Coke in original state. Per cent.	Coke after treatment. Per cent.
Sulphur in state of sulphuret,	0·440	0·250
Sulphate,	0·065	0·075

He then treated coke ground to powder in the same manner, and found an entire absence of both sulphates and sulphurets. His experience shows that it is difficult to obtain *in practice* 50 per cent. of desulphurization.

With regard to steam PHILIPPART states, from practical experiment, the following results:—

	Sulphur in original Coke.	In Coke after process.
As sulphide,	0·575 per cent.	0·45 per cent.
As sulphate,	0·050 "	0·04 "

He hence considers steam a good desulphurizer; but the necessity of keeping the coke at a red heat, and the want of action unless the coke is broken small, render the obstacles to its application very great, and besides this, it is not safe to calculate upon removing more than one-fifth of the sulphur.

He considers the treatment with common salt likely to produce a more complete desulphurization, but this will not compensate for the expense of the agent employed in the reaction. PHILIPPART has further conclusively satisfied himself that the treatment of coke with hydrochloric or other acids cannot be commercially applied.

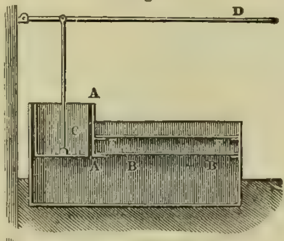
With regard to the treatment with oxygen at ordinary atmospheric pressure, PHILLIPART'S experiments show that when this is applied so as not to produce a loss of carbon, not more than 7½ per cent. of the sulphur of the sulphides is removed.

The French engineers, GRANDIDIER and RUE, have attempted the application of air under pressure. The coke was run in wagons into large cylinders, but the results have not been found to be satisfactory.

With regard to the use of carbonate of sodium and chloride of sodium, the author from whom these remarks have been abstracted says, that the treatment of coke with soda cannot be considered as possible from a commercial point of view.

Washing.—Of the improvements for the purpose of producing a better quality of coke, the method of washing deserves notice. In France and Belgium the veins of coal are intimately blended with shaly matters near the walls, or intersected with such substances, which are in some instances harder, though in others more friable than the coal. In this state it could not be advantageously employed for coking; and with a view to economy it is customary to assort the coal into three classes or qualities. This is done by means of an apparatus called a *gailleterie*, consisting of strong sieves, upon which a stream of water falls. The largest pieces, called *gaillettes*, about 2 cubic inches in size, are retained in the first sieve; the *gailletins*, or second size, are composed of pieces about one-third of a cubic inch; and the third, or *tails*, consist of fragments smaller than these. From the first, the pieces of schist may be easily removed by picking; but the second, in which considerable quantities of stones and other matters are retained, cannot be so purified; whilst in the third, or tails, all the earthy, pyritous, and other friable impurities accumulate. MARSILLY'S experiments showed that the coals from the basins of the Mons and of Valenciennes, when so treated, and the products converted into coke, gave a result manifesting considerable difference as to quality. The first selection, or *gailleterie*, afforded a good coke, its ashes averaging from 6 to 7 per cent.; the coke from the next selection was not so good, and retained from 7 to 11 per cent. of mineral matters. The original coal, when carbonized without any preparation, yielded a product intermediate between these. It was inferred from such results that the substances which affect the purity of the coal are those which are more friable, and that, by a proper course of treatment, they might be concentrated in the "breeze" or final refuse of the coal. To effect this, the coals are subjected in some places to a process of washing, similar to that followed in the purification of minerals. In the pyritous coal localities of the Vosges this process has been practised for a considerable period; but it was not adopted in other collieries till about 1840, when it was introduced into the coal districts of St. Etienne, Rive-de-Gier, and at Mons and Valenciennes.

Fig. 49.



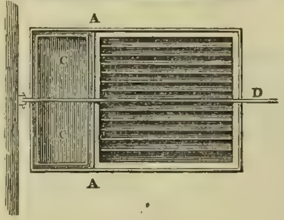


Fig. 50.

Fig. 49, annexed, shows a side elevation of a simple machine used for this purpose; and Fig. 50 a plan of the same. It is a rectangular wooden trough, divided into two unequal compartments by a partition, A A, which does not extend to the bottom. In the larger compartment, a grate, B B, of osiers, iron wire, or perforated zinc, is fixed, and upon this the coals are cast. The trough is filled with water till it rises to the coals on the perforated shelf, when the washing is proceeded with. This is effected by moving the piston-rod attached to a box, C, filling the smaller compartment, up and down in the water by means of an arrangement of levers, D, as seen in the drawings, a movement which has the effect of forcing the water higher in the larger division of the trough, and of floating the lighter portions of the materials, so as to cause the schistose matter to gravitate to the bottom by the motion produced by the alternate rise and fall of the water. When the action has been continued for a sufficient length of time, the superior layer of purified coal is removed from the under layer of impurities. To render this part of the work less troublesome, another perforated bottom, F F, is fixed over the grate, B B. During the washing, the pyritous and other matters fall through the first, F F, and accumulate upon the second one, whilst the purified coal still rests upon the former. Under favourable circumstances, three men can work off from 20 to 25 cubic yards of coal in the space of twelve hours by this machine. The water is drawn off from time to time, and supplied by a proper adjustment of stopcocks, &c.

The apparatus employed at Commentry for washing the coal is, on the whole, simpler than the preceding. Figs. 51 and 52 show a plan and elevated section of the apparatus. The pipe, R S, conducts the water by the connecting pipes, T T T, to the stages where the fuel is washed, and which are represented at A B C D, A′ B′ C′ D′, &c. The coals are deposited in the upper compartment of those beds, as at A B, A′ B′, and when the water passes through, the larger pieces are retained by the gratings which divide these from C C′; while those pieces which pass through the openings of the first grating are retained in the second, and so on, the water finally passing off by the exit pipe, E F.

Fig. 51.

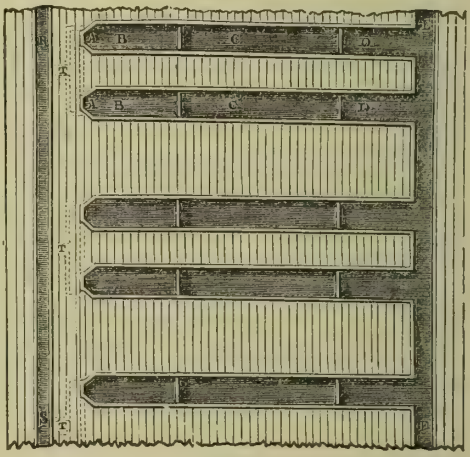
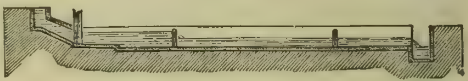


Fig. 52.



The following is an account of a coal washing and sorting machine, described by MAX EVRARD in the "Bulletin de la Société d'Encouragement," January, 1875, p. 30, and abstracted in the "Proceedings of the Institute of Civil Engineers," vol. xl.:—

"The machine is used for the simultaneous washing and sorting of coal, as it is taken from the mine mixed with other material. This is accomplished by tipping the charge from the mine into a large hopper provided with a grating which arrests the largest pieces of coal; the remainder passes into a deep cylinder of boiler plate, partly filled with water, through which the coal descends to a perforated piston with which the cylinder is fitted. In sinking through the water the coal becomes arranged in layers in the order of the sizes of the pieces, the largest lying at the bottom; stones and small pieces of rock, being of greater specific gravity than the coal, sink more quickly, pass through the perforated piston, and are collected in a receptacle for that purpose. The boiler-plate cylinder dips for about half its length into a second cylinder, also of plate iron, and of about twice its diameter, their connection being rigid and steam-tight. This latter cylinder contains water to near five-sixths of its height, from which the former cylinder, which is open at the end, receives its supply.

"There is fitted into the upper surface of the large cylinder a steam pipe, which conveys steam, at a pressure of about 10 lbs. per square inch, to the surface of the contained water, for the purpose of depressing the latter and thereby raising it in the smaller cylinder. The perforated piston which carries the load of coal is supported by a rod, fitted at its lower end with a small piston working in a hydraulic cylinder under pressure ; this cylinder occupies the central portion of the smaller plate-iron cylinder, and is fixed to bearers fastened to the larger cylinder. The upper portion, a length of about 3 feet of the cylinder which carries the charge of coal, is made separate from, and capable of moving over, the lower portion, upon horizontal guides fixed to the building in which the machine is contained, and along these guides it is pulled backwards and forwards by small pistons working in hydraulic cylinders.

"The operation of the machine is as follows:—Steam is first turned into the large cylinder, and the water therein depressed and forced upwards in the smaller cylinder to near the height of the joint between its lower fixed and its upper movable portion. While the water is maintained at this height, the charge of coal is tipped into it from a small wagon. It descends on to the perforated piston, which is at its lowest position, the stones and larger pieces of coal reaching it first, and the charge thus becoming partly sorted. Steam is now turned off, and that left in the cylinder is condensed, forming a partial vacuum, which causes the water to pass from the smaller cylinder through the coal and refill the large cylinder. Intermittent ascending and descending currents are thus directed through the charge of coal, by turning the steam on or off as many times as may be necessary to clean and classify it. After the steam is turned off for the last time, the mass is allowed to stand for a period of from two to five minutes. By means of the hydraulic pressure cylinder, the entire mass is then raised sufficiently to allow of the upper layer of fine material and dirt to be directed into a trough, by the horizontal movement of the upper portion of the cylinder. After the first operation the movable portion of the cylinder is returned, and the charge raised sufficiently to admit of the removal of another layer, or of the whole by the return motion of the cylinder. The trough through which the coal passes into small wagons is fitted with a grating to allow the water to drain from the coal into a receiver, by which it is conducted into a large settling tank, where it is cleared of mud and stones, and afterwards again used in the cleaning cylinder. Suitable tanks are provided by which the proper supply of water is continually passed into the washing cylinder. The quantity of steam used per day in cleaning about 200 tons of coal, including power used in supplying water under pressure for raising the washed coal, is about equivalent to 4 horse power.

As already stated, it is evident that coke, like the coal itself, will exhibit considerable difference, both in the nature and percentage of its constituents. A glance at the analytical tables already given will show the causes of this difference. It will therefore be unnecessary to transcribe here analytical results of the composition of coke, further than may be sufficient to indicate the usual qualities supplied to the manufacturer. Of these, nineteen analyses are subjoined:—

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Carbon,..................	95·51	85·85	90·53	94·21	93·41	93·05	89·87	84·82	96·42	97·60
Ashes,....................	2·85	12·07	8·46	5 10	5·80	5·37	8·35	14·40	2·75	1·55
Sulphur,..................	1·64	2·08	1·01	0·69	0·79	1·58	1·78	0·78	0·83	0·85
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.
Carbon,..................	94·08	92·44	89·69	91·16	93·54	91·49	94·31	94·67	92·70
Ashes,....................	5·04	6·00	8·35	7·65	5·70	7·05	4·97	4·26	5·70
Sulphur,..................	0·88	1·56	1·96	1·19	0·76	1·46	0·72	1·07	1·60
	100 00	100·00	100·00	100 ·00	100·00	100·00	100·00	100·00	100·00

ARTIFICIAL FUEL.—In most of the operations of coal-mining, as also in coking establishments, much refuse accumulates which is frequently very rich in combustible matter; but owing to its being in small dust or powder, it cannot be used in the furnace by itself. A similar waste attends the manufacture of wood and peat charcoal, and without the aid of some cohesive matter this considerable portion of the original fuel becomes useless.

Attention has for a long time being directed to the means of economizing such products in countries where fossil fuel is scarce, and this has not been confined to the "breeze" or small refuse matter of the charcoal manufactory, but has been extended to such bodies as sawdust, wood shavings, and other combustibles. In the district adjoining the Caspian Sea, where petroleum springs are abundant, the inhabitants manufacture a fuel by impregnating clay with the combustible fluid; the clods are afterwards burned in an ordinary hearth. By the gradual evaporation and combustion of the hydrocarbons, a fire of considerable intensity results. Indeed, the various contrivances which now come under the notice of the chemist, with a view to the production of artificial fuel, are little more than a copy or counterpart of the method adopted by the Orientals for solidifying the naphtha. The Norwegians have long economized the large quantities of sawdust which they produce, and convert it into a household fuel by incorporating it with ordinary clay and a little tar, and moulding the whole into bricks. Of late years attempts have been made in this country to introduce a similar practice: inventors have proposed to employ sawdust, brushwood, shavings, spent tanner's bark, and the like substances, in the manufacture of fuel and combustible gases; but hitherto the speculation has not succeeded. The principal ingredients which are taken for the production of artificial fuel are small coal or slack, friable anthracite, the refuse or "breeze" from charcoal and coke ovens, and peat, all of which are mixed with more or less pitch tar, or refuse fatty bodies. The product of some of these ingredients is found in many respects superior to natural fossil fuel, and may be used where the highest temperatures are required. For generating steam, a fuel carefully manufactured with small or refuse coal and pitch, or substances of a similar nature, is often preferred to ordinary steam coal, as it offers conveniences for stowage which coal does not, whilst its heating power is equal to, if not greater than, that of the mineral fossil.

In the nineteenth volume of the "Annales des Travaux Publics de Belgique" there is a very interesting and clear exposition of the subject of artificial fuel by FRANQUOY. The author, quoting the conditions exacted by the Belgian state railways, writes: "the bricks should be hard, sonorous, homogeneous, almost devoid of odour, and as little hygrometric as possible. Their weight should be from 9 to 10 kilogrammes (20 to 22 lbs. nearly) as a maximum. There should never be more than 5 per cent. of dust from breakage, and the mean density should be 1·2. They should light and burn easily with a clear intense flame, without becoming disintegrated, and producing only a light smoke, with a maximum of 9 per cent. of ash."

The manufacture consists, first, in washing the coal slack and dust free from schists and pyrites, from which it is never exempt; secondly, in mixing this with some cementing material; and thirdly, the compression and moulding into blocks of a regular and convenient size.

The agglutinative substances are those which give cohesion to coal naturally, and which separate on distillation—that is, tar and its derivatives, pitch and resin.

According to Professor NOLLET of Brussels the cementing depends on four principles: molecular attraction, in virtue of which the surfaces of solids in close approximation adhere; the employment of sticky substance; the property of certain elements of disengaging oxygen in the gaseous state, either through chemical or physical action, and thus producing vivid combustion in substances containing either too much hydrogen or carbon, and preventing the formation of smoke; the power which substances rich in hydrogen and carbon have of rendering more combustible substances which are poor in these elements.

Physical action alone can bind small moist coal, reducing its ordinary volume a half. High temperature is a useful aid; and in this manner caking coal has been used to bind anthracites. The sticky substances are either fatty, soapy, or resinous. The results obtained with the first of those, comprising the usual vegetable and animal fats, have not given favourable results with reference to cohesion. In combining the fatty substance with potassium and sodium the results have been satisfactory as regards cohesion, but their employment has been far from economical. The employment of resin alone has not been found to be satisfactory, although, where combined with fat, the result is as satisfactory as when tar is employed.

For the evolution of oxygen there have been employed potassic nitrates and chlorates, and chloric and chloronitric acid, as well as some metallic peroxide, and notably that of manganese. An addition of 1 to 5 per cent. of nitric acid or potassic manganate allows bitumen and oils to burn without the disengagement of smoke or smell.

Such matters as glue and horn clippings, when dissolved in a solution of potassium or sodium, communicate much cohesion and improve combustion, especially when mixed with resinous matter.

Mucilaginous substances are prepared from the cereals and farinaceous vegetables: from lichens, leaves, and roots, either in hot or cold water. These substances, it appears, not only cement together the coal dust, but produce in preparation in the furnace such hardness as to form the material into coke.

In France a very fair quality of charcoal is prepared with the refuse from the charcoal furnaces by mixing it with other substances, such as charred peat, spent tan, and the like, adding tar or pitch. The course of procedure is to grind the solid with the fluid ingredients into a homogeneous pasty mass, which, after being moulded and dried in the air, is subjected to heat in close vessels, and all volatile gases expelled. In the machine used, about 6000 or 7000 gallons of the mixture are prepared in twenty-four hours, and the force required to work it is calculated as one horse. From 7 to 9 gallons of the tar is doled out to about 2 cwts. of charcoal powder.

After the mixture is prepared, the pasty mass is moulded into quadrangular or circular masses by moulds into which it is introduced, and therein submitted to pressure by means of a heavy log or beam of wood, which carries pistons that work into those frames. In this way the operation of moulding goes on without interruption. An equivalent of six horse-power is required to work the machine employed, but with it one man and four women can produce about 450 bushels of the fuel in a day.

After the moulding, the next operation to which the material is subjected is the drying, which is merely an exposure of from two to three days to a current of air.

The carbonization of the bricks is effected in a kind of muffle furnace. The first effect of the heat is to eliminate moisture from the charring mass; this is followed by the appearance of some hydrocarbons, all of which escape from the cylinders or boxes by small apertures, about the time that the cylinders are beginning to become red-hot. Air is then admitted cautiously, whereby the evolved gases are burned, giving out as much heat as is sufficient to complete the operation.

Waste cuttings, brushwood, and such materials as could not be employed in the manufacture of ordinary charcoal, may be carbonized and then turned to profitable account in the manner just described.

The same principle is developed in the manufacture of artificial fuel from refuse coal or slack, and also from the waste matter of the coke ovens. In either case, it is necessary to mix them with substances which will give a sufficient consistency to the mass to cause the particles to adhere whilst coking or burning in the open or furnace grate. In selecting the cementing material, there are some who do not confine themselves to oleaginous, fatty, or tarry matters, but employ also loam, hydrate and sulphate of lime, and various other mineral substances, whilst others—and doubtless this is the best course to adopt—discard the use of all such bodies; and by a judicious admixture of two varieties of coal, or by operating upon the coal in a particular way, cause it to adhere, and so bring it into such a form as will admit of its being burned as ordinary fuel, or coke. The most important of the artificial fuels will here be alluded to.

Wylam directs, in his patent for the manufacture of artificial fuel, that small coal be mixed with pitch and the compound afterwards moulded. The proportions in which these ingredients are taken are 4 parts of slack to 1 of pitch. By means of edge stones, or other machinery, the pitch and coal are ground together, or otherwise mixed, and the mass is put into a large hopper, from which it passes into a retort, which is maintained at a red heat by hot air—the material becomes more or less liquefied during the passage from one end to the other.

This pasty mass having fallen into a receiver, is agitated by the arms, to prevent it hardening into lumps before it is moulded.

If the pitch be not well distilled, and a portion of the oleaginous constituents are retained, the fuel, when stowed where the temperature is somewhat elevated, is apt to ignite spontaneously, in consequence of the evolution and oxidation of those matters. The tendency to this is always greater when fatty matters or oils have been used with the small coal. Numerous instances of the spontaneous combustion of artificial fuels, and even of coals, have been traced to this cause.

To guard against this danger, Warlich heats his patent fuel, which is prepared nearly like the foregoing, to a temperature of from 400° to 600° Fahr., in order to dispel all the inflammable ingredients. By this means he produces a species of coke which, even in tropical climates, is quite safe. He mixes a little salt or alum with the combustible ingredients before moulding, that too much smoke may not be evolved during the ignition in the grate.

At Blanzy the waste coal is worked into an artificial fuel in the following manner:—The coal is screened or purified from fragments of pyritous and shaly substances, by placing the matter upon a metal sieve, fixed in a large vat, communicating with a pump by means of a large pipe. When the pump is worked, the water is agitated in the vat, and this agitation causes the matter on the sieve to arrange itself in the order of its density, the heavier particles falling through to the bottom of the vat. After the matter remaining on the sieve is drained, it is removed and crushed between rollers, so as to render it more homogeneous. The coal thus crushed is mixed with 7 or 8 per cent. of tar, and moulded into bricks.

Several other patent processes for solidifying small coal and tar into a substance fit to be used as fuel, differ but slightly from the foregoing. The process of H. Bessemer is considerably superior to any of these, as it enables proprietors to convert *the whole of the combustible material* into first-class coal, without suffering the loss which is invariably attendant upon colliery operations. It consists in heating small bituminous coal to a temperature at which it fuses, and while in this state moulding it into convenient shapes. By this means the use of mineral, tarry, or oleaginous cements are dispensed with, and a fuel is produced nearly equal in heating qualities to the round coal of the working, and much more convenient for stowage, from its being in regular shapes. In this operation a series of very ingenious contrivances are brought into requisition, and made to perform the work with admirable regularity.

Barker's artificial fuel, which forms the subject of a patent, consists in the treatment of coal, coke, peat, charcoal, tar, sawdust, and woody fibre in a state of powder, so as to produce solid fuel, by the employment of starch, or yeast, or vegetable substance destitute of gluten. In his patent, 1547, of 1865, the patentee describes the method he prefers for forming the mucilaginous substance. This is added to the powdered coal in the proportion of 1 to 8, and the mass is thoroughly incorporated, and then formed into blocks and dried. The mixture takes place in a pugmill, and the drying takes place in from nine to twelve hours, at a temperature of from 250° to 300° Fahr. This fuel is described in a paper read before the South Wales Institute of Engineers in 1867, by A. Bassett, past president.

Gaseous Fuel.—In the early portion of the present century gas seems to have been first employed as a fuel in metallurgical operations. It was employed in the first instance on the Continent of Europe. Lampadius, in 1801, was the first to propose the utilization of waste gases, but it appears that it was not until thirty years afterwards that he carried his proposal into practice. In the meantime Aubertot had employed the waste gases from blast furnaces for several purposes, chiefly metallurgical. These applications did not attract much attention, and can hardly be considered otherwise than tentative. In 1837, however, Faber made a reverberatory furnace for puddling pig metal, specially applied to the utilization of the waste gases from the blast furnace, which appears to have had considerable application of a local kind. What was against it was the prejudicial effect on the puddling process, caused by the variations in quality and quantity of the blast furnace gases. This induced BISCHOF, a year or two later, to make experiments on the production of gas in a separate furnace, since called a generator or producer, and on its after combustion in a special chamber with air. These results were developed to a certain small extent, but it is to the SIEMENS' regenerative gas furnace and producer, which may be considered as perhaps the most economical metallurgical furnace in use, that we would draw special attention here.

The first application of regenerators, or heat-accumulators, appears to have taken place in this country. Dr. STIRLING of Dundee patented, in 1817, an air engine, in connection with which was a regenerator, which consisted of thin vertical strips of glass or metal, placed in close juxtaposition. The principle of action is, first, the lowering of the temperature of a fluid by its giving up its heat to the regenerator, and afterwards raising it by a restoration to it of the greater portion of the heat previously stored up. JAMES STIRLING, in connection with his brother, improved this air-engine (chiefly by the employment of compressed air), and an engine of forty-five horse power was started at the Dundee Foundry in 1843, and worked economically. On the foundry's changing hands, and after some air vessels had given way, the engine was removed. In this engine the temperature was changed at constant volume.

The next application was made by Dr. C. WILLIAM SIEMENS in 1847, in which year was patented his regenerative steam engine and condenser, with the employment of superheated steam. The efficiency of this engine increases with the temperature employed, and the difficulty of employing intense heat has been the only cause which has hindered its extensive application.

In 1852 Captain ERICSSON introduced his regenerative air engine, which differed from STIRLING'S principally, in theory, in the alteration of temperature taking place at constant pressure.

The first tentative application of regenerators to furnaces was made in 1856 by FREDERIC SIEMENS. In this arrangement solid fuel was used, which was burnt intermittently on two separate hearths, having the furnace between them. The air passed from below through a passage to the first regenerator, thence to the burning fuel; the waste products of combustion, after heating the furnace, gave up their remaining heat to the second regenerator, and thence passed to the chimney. The current was reversed by means of valves specially constructed for the purpose, and the air was made to pass in the opposite direction, the second fireplace being at the same time supplied with fuel. By thus reversing the direction of the current from time to time, heat necessarily accumulated in the furnace, except in so far as it was absorbed by the material to be heated, and was lost by radiation and conduction. It is stated in the specification that the saving of fuel will be increased according as the intensity of temperature required to be obtained is higher.

In a specification which was filed in the following year at the Patent Office, certain improvements were made on the last-named invention, the chief one being a plan of heating a single chamber continuously by means of one fireplace, in combination with the alternate reversals of currents through the regenerators, without reversing the direction of the flame. There is also described a method for heating a chamber with air instead of with the products of combustion, which is of advantage in special cases. In the specification of this invention there is the first glimmering idea of a separate producer, and a means is explained for making the flame vary in quality, a mechanical arrangement for regulating the supply of fuel is described, and an automatic arrangement for working the valves. It is also advised to place the regenerators at a lower level than the material to be heated, in order to the attainment of a plenum of pressure in the furnace.

It was in 1861, however, that the regenerative gas furnace, as now used, was introduced by C. WILLIAM SIEMENS, with a separate gas producer, gas and air regenerators, and an overhead cooling-tube, to which we shall not refer particularly at present, as it will form the subject of a later description.

In 1866 a special application of the furnace to the melting of steel in pots was introduced; and in 1868 horizontal regenerators were employed, the gas regenerator being placed uppermost; and there is described in the specification a small mixing chamber for the air and gas, which, preventing combustion therein, directed the flame in a jet through a tapering aperture across the bed. The horizontal regenerators allowed of their being constructed in situations where, owing to dampness of soil, it was impossible without great expense to obtain the dry foundation necessary for the vertical. This arrangement also affords facilities for cleansing the regenerators from dust and deposit, for which purpose manholes are used; and when it is desirable that the furnace should be accessible from three sides, both pairs of regenerators communicate with the same end of the furnace. The application of gas to annealing furnaces and to steam boilers is also described.

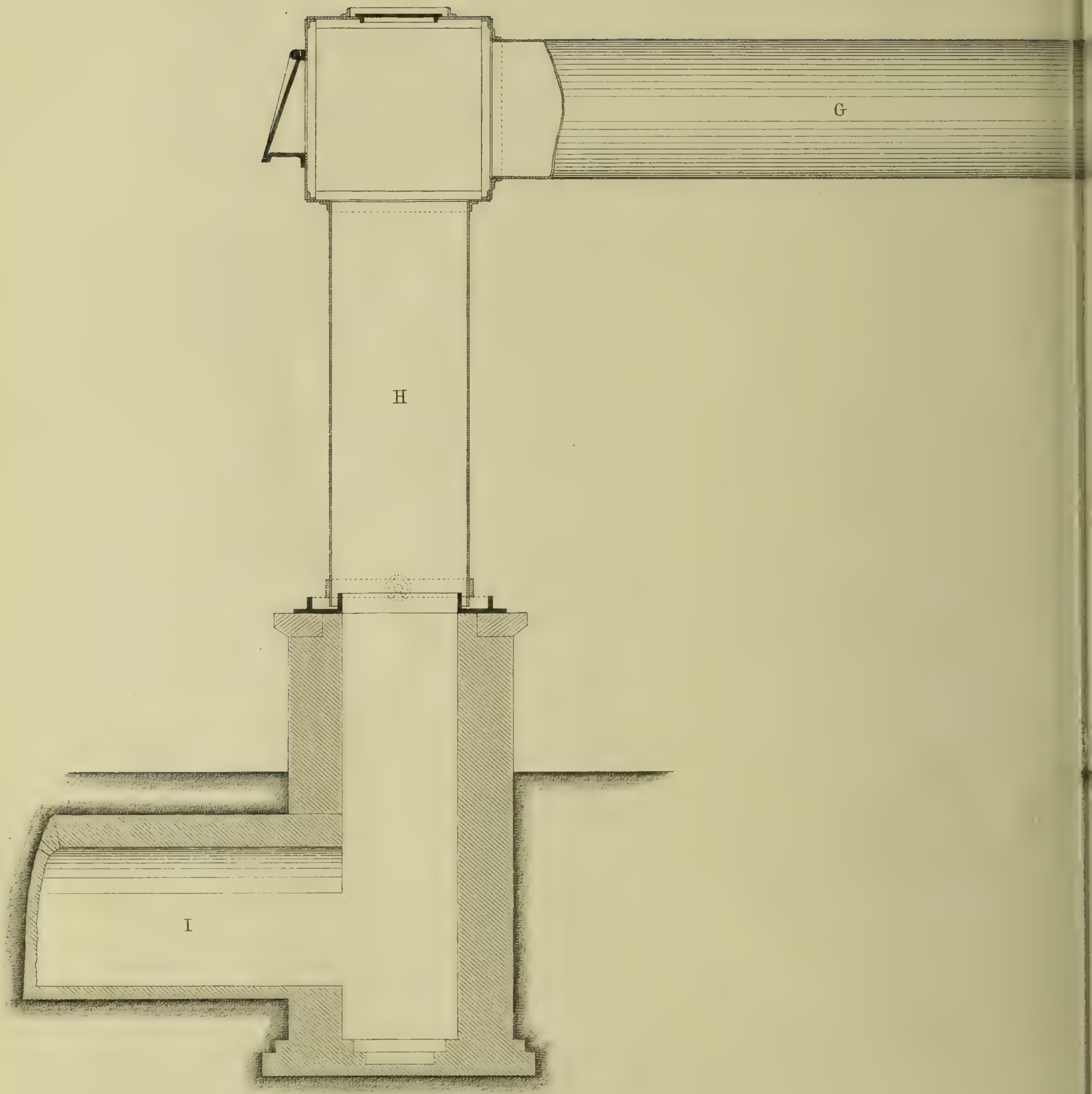
In 1870 a new form of producer was introduced, in which the volatile hydrocarbons were made to pass near the foot of the producer, where by being reheated they were formed into permanent gases; and the continuous glass melting furnace, which will be specially described under GLASS, was introduced.

The following description of the gas producer and regenerative gas furnace is abstracted from a lecture delivered by C. W. SIEMENS before the Fellows of the Chemical Society, May 7, 1868, "On the Regenerative Gas Furnace as applied to the manufacture of Cast Steel."

The regenerative gas furnace consists of two essential parts —the gas producer, in which the coal or other fuel used is converted into a combustible gas; and the furnace, with its "regenerators" or chambers for storing the waste heat of the flame, and giving it up to the incoming air and gas.

Any combustible gas might be burned in the regenerative furnace. I have used ordinary lighting

FUEL.



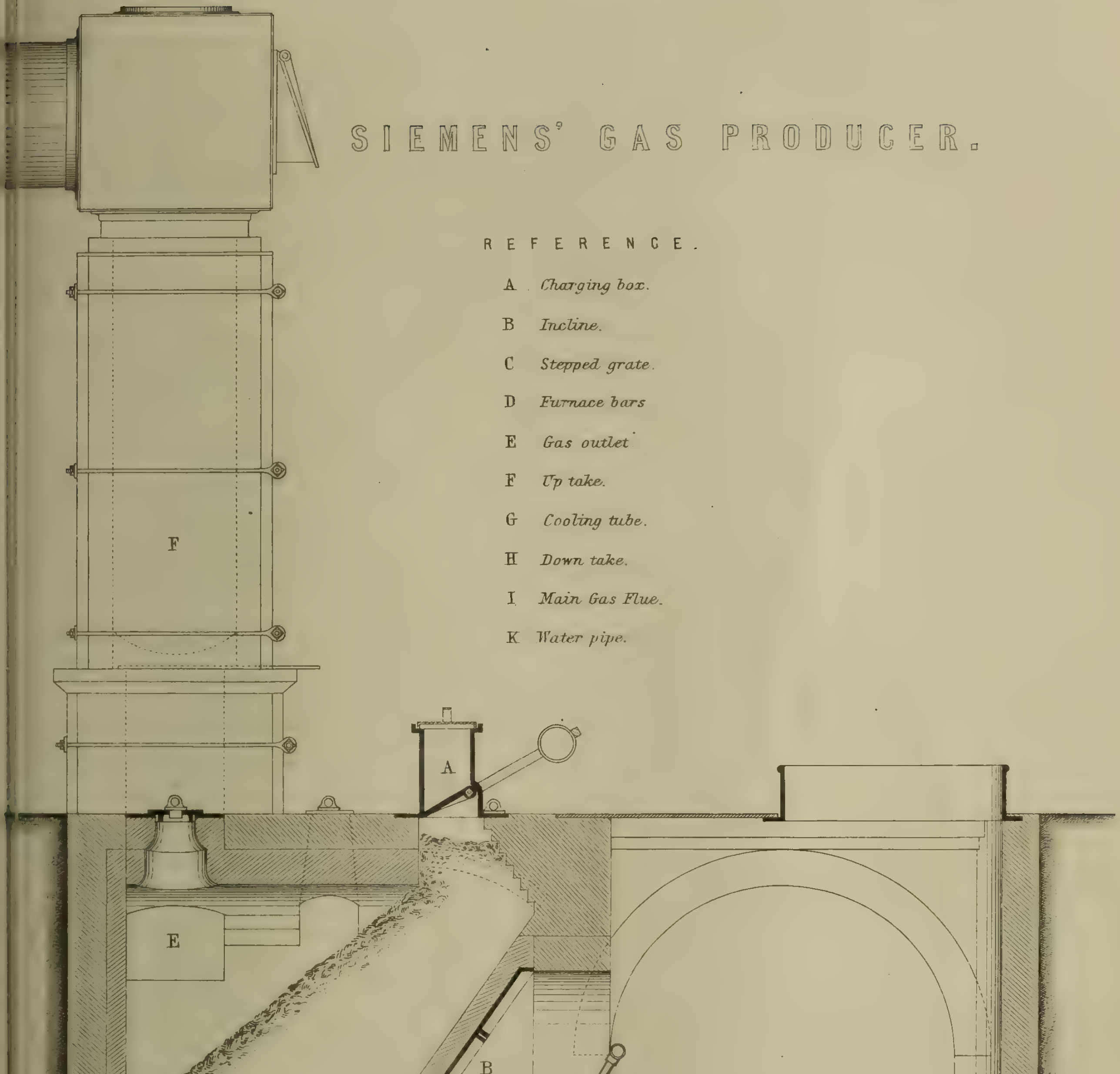
J. B. LIPPINCOTT

PLATE I.

SIEMENS' GAS PRODUCER.

REFERENCE.

A	*Charging box.*
B	*Incline.*
C	*Stepped grate.*
D	*Furnace bars*
E	*Gas outlet*
F	*Up take.*
G	*Cooling tube.*
H	*Down take.*
I	*Main Gas Flue.*
K	*Water pipe.*



PHILADELPHIA.

gas very successfully on a small laboratory scale, but it is far too costly to be employed in larger furnaces; and the only gas generally available is that generated by the complete volatilization of coal, wood, or other fuel, with admission of air in a special "gas producer." Any description of carbonaceous matter may be worked in a suitable gas producer, and will afford gas sufficiently good for the supply of even those furnaces in which the highest heat is required. Coal is the fuel chiefly used for gas furnaces in England; small coke has been employed in some cases, as in gas-works, where it is to be had at a cheap rate; wood is used in France, Bohemia, and Spain; sawdust in Sweden, furnishing gas for welding and other high-heat furnaces; lignite in various parts of Germany; and peat in Italy and elsewhere; this last being applicable with the greatest relative advantage.

A SIEMENS' gas producer, suitable for burning non-caking slack, is represented in Plate I.

In form it is a rectangular fire-brick chamber, one side of which is inclined at an angle of from 45° to 60°, and is provided with a grate at its foot. The fuel is filled in at the top of the incline, and falls in a thick bed upon the grate. Air is admitted at the grate, and as it rises slowly through the ignited mass, the carbonic acid, first formed by the combination of the oxygen with the carbon of the fuel, takes up an additional equivalent of carbon, forming carbonic oxide, which diluted by the inert nitrogen of the air and by a little unreduced carbonic acid, and mixed with the gases and vapours distilled from the raw fuel during its gradual descent towards the grate, is led off by the gas flue to the furnace. The ashes and clinkers that accumulate on the grate are removed at intervals of one or two days.

The composition of the gas varies with the nature of the fuel used and the management of the gas producer. That of the gas from the producers at the Plate Glass Works, St. Gobain, France, burning a mixture of three-quarters caking coal and one-quarter non-caking coal is as follows, by an analysis dated July, 1865:—

	Volumes.
Carbonic oxide,	23·7
Hydrogen,	8·0
Carburetted hydrogen,	2·2
Carbonic acid,	4·1
Nitrogen,	61·5
Oxygen,	0·4
	99·9

The trace of oxygen present is no doubt due to carelessness in collecting the gas, or to the leakage of air into the flue; and allowing for this, the corrected analysis will stand as under:—

	Volumes.	
Carbonic oxide,	24·2	34·6
Hydrogen,	8·2	
Carburetted hydrogen,	2·2	
Carbonic acid,	4·2	65·4
Nitrogen,	61·2	
	100·0	

Only the first three of these constituents, say 35 per cent. of the whole, are of any use as fuel, the nitrogen and the carbonic acid present merely diluting the combustible gases. It is the presence of this large proportion of inert gases, which must be heated to the full temperature of the flame, that renders it so difficult to maintain a high heat by gas of this description burned in the ordinary way. In using such gas in a regenerative furnace the presence of so large an amount of nitrogen is not objectionable, as the heat it carries off is given up again to the air and gas coming in.

The gas as it passes off from the fuel contains also more or less aqueous vapour, which is got rid of by cooling it, with some tar and other impurities, and a small quantity of suspended soot and dust.

Any air drawing in unburned through a hole in the mass of fuel, reduces the value of the gas by burning the carbonic oxide again to carbonic acid. To prevent the indraught of air in this way at the side of the grate, I have found it very advantageous to set the side walls of the gas producer back, forming a broad step about 9 or 10 inches above the grate; any air creeping up along the wall is thus thrown into the mass of fuel and completely burned. The effect of this feature in the form of the producer on the quality of the gas has been very striking.

Three-tenths of the total heat of combustion of solid carbon are evolved in burning it to carbonic oxide; but in the gas producer a small portion only of this heat is really lost, because it is in a great measure taken up and utilized in distilling the tar and hydrocarbon gases from the raw fuel; and it may be still further economized, especially in burning a fuel, such as coke or anthracite, which contains little or no volatile matter, by introducing a regulated supply of steam with the air entering at the grate. This is effected very simply by keeping the ash-pit always wet. The steam is decomposed by the ignited coke, and its constituents, hydrogen and oxygen, are rearranged as a mixture of hydrogen and carbonic oxide, with a small variable proportion of carbonic acid. Each cubic foot of steam produces nearly two cubic feet of the mixed gases, which, being free from nitrogen, have great heating power and form a valuable addition to the gas. The proportion of steam that can be advantageously introduced into the gas producer is, however, limited, as it tends to cool the fire, and if this is at too low a heat, much carbonic acid is produced instead of carbonic oxide, causing waste of fuel.

From the comparatively high temperature of the gas as it rises from the fuel (300° C. to 500° C.), and from its comparatively low specific gravity, it is considerably lighter than atmospheric air, and ascends into the upper part of the producer with a slight outward pressure. It is necessary to maintain this pressure through the whole length of the gas flue, in order to insure a free supply of gas to the furnaces, and to prevent its deterioration in the flue, through the indraught of air at crevices in the brickwork. The slight loss of gas by leakage, which results from a pressure in the flue, is of no moment, as it ceases entirely in the course of a day or two, when the crevices become closed by tar and soot.

Where the furnace stands so much higher than the gas producer, that the flue may be made to rise considerably, the required plenum of pressure is at once obtained; but more frequently the furnaces and gas producers are placed nearly on the same level, and some special arrangement is necessary to maintain the pressure in the flue. The most simple contrivance for this purpose is the "elevated cooling tube." The hot gas is carried up by a brick stack to a height of 8 or 10 feet above the top of the gas producer, and is led through a horizontal sheet-iron cooling tube, of not less than 60 square feet of surface per gas producer, from which it passes down either directly to the furnace, or into an underground brick flue.

The gas rising from the producer at its high temperature is cooled as it passes along the overhead tube, and the descending column is consequently denser and heavier than the ascending column of the same length, and continually over-balances it. The system forms, in fact, a syphon in which the two limbs are of equal length, but the one is filled with a heavier fluid than the other.

This method of obtaining a pressure in the gas-flue by cooling the gas, has been objected to as throwing away heat that might be employed to more advantage in the furnace; but this is not the case, because the action of a regenerator is such, that the initial temperature of the gases to be heated has no effect on the final temperature, and only renders the cooling of the hotter fluid more or less complete. The only result, therefore, of working the furnace with gas of high temperature is to increase the heat of the waste gases passing off by the chimney flue. The complete cooling of the gas results, on the other hand, in the great advantage of condensing the steam that it always carries with it from the gas producer; and in the case of iron and steel furnaces, in burning wet fuel, it is absolutely necessary to cool the gas very thoroughly, in order to get rid of the large amount of steam that it contains, which, if allowed to pass on to the furnace, would oxidize the metal.

There is undoubtedly a certain waste of heat, which might be utilized by surrounding the cooling tube with a boiler, or by otherwise economizing the heat it gives off, as, for instance, in drying the fuel; but the saving to be effected is not very great.

In erecting a number of gas producers and furnaces, it is generally preferred to group the producers together, leading the gas from all into one main flue, from which the several furnaces draw their supplies. The advantages of this are saving of labour and convenience of management, from the gas producers being all close together, and greater regularity in working, as the furnaces are seldom all shut off at once; nor is it likely that all will require at the same time an exceptional amount of gas.

From the fact that the gas producers may be at any distance from the furnaces that they supply, if they are only at a lower level, it would be perfectly practicable to erect them in the coal mine itself, burning the slack and waste coal *in situ* (in place of leaving it in the workings as is now often done), and distributing the gas by culverts to the works in the neighbourhood, instead of carrying the coal to the different works and establishing special gas producers at each. In rising to the mouth of the pit, the gas would acquire sufficient pressure to send it through several miles of culvert.

In the regenerative furnace the gas and air employed are separately heated by the waste heat of the flame, by means of what are termed "regenerators" placed beneath the furnace. These are four chambers, filled with fire-bricks, stacked loosely together, so as to expose as much surface as possible; the waste gases from the flame are drawn down through two of the regenerators, and heating the upper rows of bricks to a temperature little short of that in the furnace itself, pass successively over cooler and cooler surfaces, and escape at length to the chimney flue nearly cold. The current of hot gases is continued down through these two regenerators until a considerable depth of brickwork, near the top, is uniformly heated to a temperature nearly equal to that of the entering gas, the heat of the lower portion decreasing gradually downwards, at a rate depending on the velocity of the current, and the size and arrangement of the bricks. The direction of the draught is then reversed; the current of flame or hot waste gases is employed to heat up the second pair of regenerators; and the gas and air entering the furnace are passed in the opposite direction through the first pair, and coming into contact, in the first instance, with the cooler brickwork below, are gradually heated as they ascend, until, at some distance from the top, they attain a temperature nearly equal to the initial heat of the waste gases, and passing up into the furnace, meet and at once ignite, producing a strong flame, which, after passing through the heating chamber, is drawn down through the second pair of regenerators to the chimney flue. The temperature attained by the ascending gas and air remains nearly constant, until the uppermost courses of the regenerator brickwork begin sensibly to cool; but by this time the other two regenerators are sufficiently heated, and the draught is again reversed, the stream of waste gases being turned down through the first pair of regenerators, re-heating them in turn, and the gas and air which enter the furnace being passed up the second.

By thus reversing the direction of the draught at regular intervals, nearly all the heat is retained in the furnace that would otherwise be carried off by the products of combustion, the temperature in the chimney-flue rarely exceeding 170° C., whatever may be the heat in the furnace. The proportion of heat carried off in an ordinary furnace by the products of combustion is generally far greater than that which can be utilized, as all the heat of the flame below the temperature of the work to be heated is absolutely lost. The economy of fuel effected in the regenerative gas furnace, by removing this source of loss, and making all the heat of the waste gases, however low its intensity, contribute to raise the temperature of the flame, amounts in average practice to fully 50 per cent. on the quantity used in an ordinary furnace, and the saving is greater the higher the heat at which the furnace is worked. In addition to this economy in the amount of fuel used, a much cheaper quality may generally be burned in the gas producer than could be used in a furnace working at the same heat, and in which the fuel is burned directly upon the grate in the ordinary way.

When the heat of the furnace is not abstracted continually by cold materials charged into it, the temperature necessarily increases after each reversal, as only a very small fraction of the heat generated is carried off by the waste gases. The gas and air, in rising through the regenerators, are heated to a temperature nearly equal to that at which the flame had been passing down, and when they meet and burn in the furnace the heat of combustion is added to that carried up from the regenerators, and the flame is necessarily hotter than before, and raises the second pair of regenerators to a higher heat. On again reversing, the higher heat is communicated to the gas and air passing in, and a still hotter flame is the result.

The temperature that may be attained in this way by the gradual accumulation of heat in the furnace and in the upper part of the regenerators appears to be quite unlimited, and the heat at which a suitably designed furnace can be worked is limited in practice only by the difficulty of finding a material sufficiently refractory of which it can be built.

Welsh Dinas brick, consisting of nearly pure silica, is the only material, of those practically available on a large scale, that I have found to resist the intense heat at which steel-melting furnaces are worked; but though it withstands perfectly the temperature required for the fusion of the mildest steel, even this is melted easily if the furnace is pushed to a still higher heat.

As the gas flame is quite free from the suspended dust which is always carried over from the fuel by the keen draught of an ordinary furnace, the brick-work exposed to it is not fluxed on the surface and gradually cut away, but fails, if at all, only from absolute softening and fusion throughout its mass. A Stourbridge brick, for example, exposed for a few hours to the heat of the steel-melting furnace, remains quite sharp on the edges, and is little altered even in colour; but it is so thoroughly softened by the intense heat, that on attempting to take it out, the tongs press into it and almost meet, and it is often pulled in two, the half-fused material drawing out in long strings. It results from this perfect purity of the flame, that where the heat is not sufficient to effect the absolute fusion of the bricks employed, the length of time is almost unlimited during which a gas furnace will work without repairs.

Another advantage in employing the fuel in the manageable form of gas is that the rate of combustion may be regulated at pleasure to produce an active heating flame of any length, from little more than two feet, as in the pot steel-melting furnaces, to thirty feet in the largest furnaces for the fusion of plate glass; and the most intense heat may be thrown exactly upon the charge, the ends of the furnace and the apertures through which the gas and air are introduced being actually protected from the heat by the currents of unburned and comparatively cool gases flowing through them, and only mixing and burning at the very point at which the heat is required, and where it is taken up at once by the materials to be fused or heated. This is of special importance in the case of those furnaces in which a very intense heat is employed.

The best size and arrangement of the bricks is determined by the consideration of the extent of opening required between them to give a free passage to the air and gas, and by the rule deduced from my experiments on the action of regenerators in 1851–52,* that a surface of six square feet is necessary in the regenerator to take up the heat of the products of combustion of 1 lb. of coal in an hour.

By placing the regenerators vertically and heating them from the top, the heating and cooling actions are made much more uniform throughout than when the draught is in any other direction, as the hot descending current on the one hand passes down most freely through the coolest part of the mass, while the ascending current of air or gas to be heated rises chiefly through that part which happens to be hottest, and cools it to an equality with the rest.

The regenerators should be always at a lower level than the heating chamber; as the gas and air are then forced into the furnace by the draught of the heated regenerators, and it may be worked to its full power, either with an outward pressure in the heating chamber, so that the flame blows out on opening the doors, or with the pressure in the chamber just balanced, the flame sometimes blowing out a little, and sometimes drawing in. The outward pressure of the flame prevents that chilling of the furnace, and injury to the brickwork, from the in-draught of cold air through crevices, which is otherwise unavoidable in any furnace worked without blast.

The action of the furnace is regulated by the chimney damper, and by valves governing the supply of gas and air, and the draught is reversed by cast-iron reversing valves, on the principle of the common four-way cock.

In considering the theory of the regenerative gas furnace and gas producer our remarks naturally commence with the latter.

The temperature of combination of pure carbon or of carbonaceous matter burning in atmospheric air, and producing carbonic oxide diluted with nitrogen, is easily calculable. Atmospheric air consists of one part by weight of oxygen, and 3·35 by weight of nitrogen. One part by weight of pure carbon requires for the production of carbonic oxide by imperfect combustion or transformation 1·3 part by weight of oxygen. It follows from this, that the weight of nitrogen which has to be heated to convert a unit weight of carbon into carbonic oxide, by combustion in the atmosphere, is $3{\cdot}35 \times 1{\cdot}3 = 4{\cdot}46$. The number of units of heat produced by the transformation of a unit of carbon into carbonic oxide is according to the best results about 2400. In order to obtain the resulting temperature by theoretical reasoning, we have to introduce the subject of specific heat, a subject which still requires much experimental consideration before it can be said that a satisfactory result has been obtained with regard to it. There is sufficient reason to know that this quantity is variable, and that it increases with the temperature. Judging from the specific heat obtained at lower temperatures, and the law of increase which it appears to follow, the mean specific heat of nitrogen betwen 0° and 1000° C. may be given as about ·38, and that of carbonic oxide as about ·35. Hence it follows that the resulting temperature of transformation of carbon into carbonic oxide burning in the atmosphere is—

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* Proceedings of the Institution of Civil Engineers, 1852–53, page 571, On the Conversion of Heat into Mechanical Effect.

$$\frac{2400}{4{\cdot}46 \times {\cdot}38 + 2{\cdot}3 \times {\cdot}35} = \frac{2400}{2{\cdot}5139} = 960^\circ \text{ C.}$$

From experiments which have been made in different states of the producer, as managed with more or less care, the temperature of the gases at the foot of the uptake from the producer appears to vary from 300° to 500° C., or taking the mean at 400° C. The difference between the above temperature of 960° and 400° is 560°, and the number of heat units representing this difference of temperature is $\frac{560}{960} \times 2400 = 1400$ units have been employed in the distillation of the hydrocarbons contained in the coal and in the decomposition of the steam supplied below the grate, thus enriching the resulting gases to exactly the same amount—the heating power of the hydrocarbons produced being the exact equivalent of the heat units employed in their production.

It has been frequently stated that the action of the gas-producer is such as to cause a loss of heat of 30 per cent. of the total heat available, carbon producing 8080 units by perfect combustion into carbonic acid, and carbonic oxide absorbing 2400 units in its production. It must be remembered, however (and this is where the error in the statement exists), that this loss corresponds to a resulting temperature of 960° C. (for if the carbonic oxide were at once utilized in the furnace at its temperature of production, no heat would be lost), whereas experiments give a mean of 400° C. as that of the producer gas. The loss, therefore, in the producers is reduced from 30 per cent. to a mean of $\frac{400}{960} \times 30 = 12\frac{1}{2}$ per cent., and a minimum hitherto attained of $\frac{300}{960} \times 30 = 9\frac{3}{8}$ per cent. It is possible, however, so to work the producers as to recover in the form of hydrocarbons and mechanical energy nearly the whole of the 30 per cent., as will be seen farther on.

The cooling tube is the means that has been employed for obtaining a pressure in the gas before the delivery of the same at the foot of the regenerators.

The following is the method of calculation to be employed for obtaining the height of the cooling tube required to produce a pressure as great as that attainable by placing the producers at a lower level in the ground. It is a general statement of the case specially referred to in the paper before the Chemical Society already cited:—

Let T be the temperature in degrees C. of the gas as it rises from the producers. t, the temperature at which it enters the uptake to the furnace. d, the specific gravity of the gas as referred to hydrogen at 0° C. The weight of gas per cubic foot at T° C., and t° C. respectively, is—

$$\frac{d \times 274}{\text{T} + 274} = w_{\text{T}}, \text{ and} \frac{d \times 274}{t + 274}\, w_t.$$

The weight of the atmosphere per cubic foot at 15° C. is ·076 lb., then the increase of pressure per foot of height in the uptake is $\cdot066 - w_{\text{T}} = \text{U}$, and the excess of pressure per foot of height, at the foot of the downtake from the cooling tube, over that at the same level in the uptake, is $w_t - w_{\text{T}} = \text{D}$. Let h be the height of heated gas column, the pressure due to which has to be attained by a height, H, of cooling tube above the level of the flue, then $\text{H} = \frac{\text{U}}{\text{D}}\, h$.

If the temperature is given on the Fahrenheit scale, for 274 above read 461, as in the following, where $\text{T} = 1100^\circ$ F., $t = 100^\circ$ F., $d = 13{\cdot}14$ and $h = 10$ feet; here H will be found equal to 14 feet nearly. In a few words, one of the effects produced by the cooling tube is the transformation of heat energy into mechanical energy, in which form it is required.

A further and important function performed by the cooling tube is the condensation of water vapour, which at a high temperature would be carried forward to the furnace, and there produce oxidation, or burning of the metal. It is thus a valuable addition to the furnace from a metallurgical point of view, where it is not only a question of consumption of fuel, but also a question of fuel as to its effects on the operations which have to be considered, or otherwise a question of flame. There is, then, from 9 to 12 per cent. of useful effect of the fuel lost before the gas enters the regenerators.

For a proper consideration of the theory, and examination of the economy of the regenerative gas furnace, a number of data would be required which are not in existence. Such as the temperature of the gas after combustion in the furnace, the quantity of heat required in any given metallurgical operation on a given weight of substance, the specific heat of substances treated at high temperatures, the loss of heat by conduction and radiation through the walls of the regenerators, the top, and walls of the furnace; these varying both with their temperature and that of the atmosphere, of which no experiments have been made, and no apparatus appears to exist for experimentalizing with.

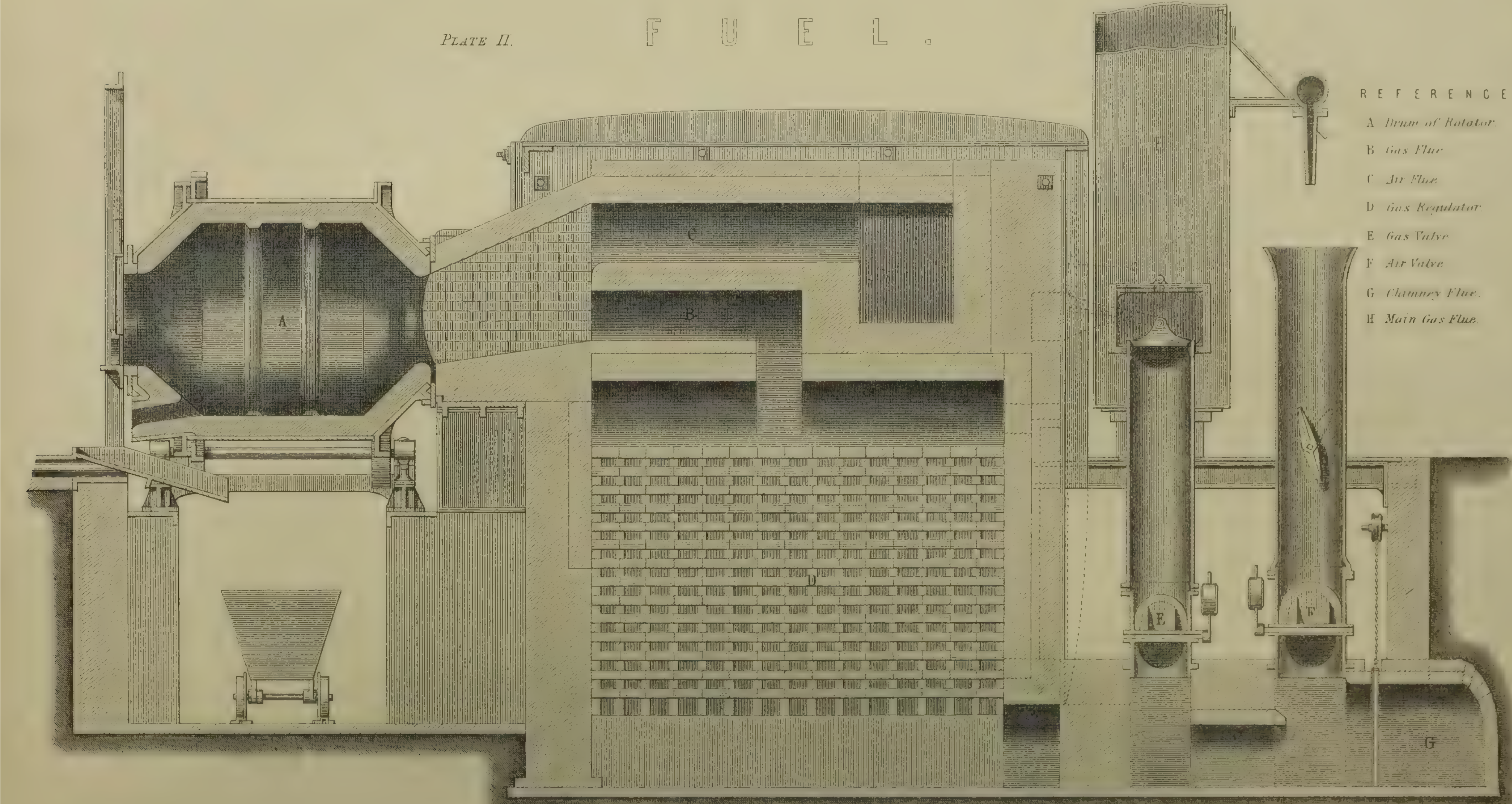
About all these matters information would be required, before anything absolute could be stated as to the economy of working of the gas furnace; its comparative economy only, then, can be treated of.

The economy of the furnace consists in the temperature of the heated gas and air, which intensity

LONGITUDINAL SECTION OF SIEMENS' ROTATORY FURNACE FOR THE DIRECT MANUFACTURE OF IRON & STEEL.

PLATE II.

FUEL.



REFERENCE.

A *Drum of Rotator.*
B *Gas Flue.*
C *Air Flue.*
D *Gas Regulator.*
E *Gas Valve.*
F *Air Valve.*
G *Chimney Flue.*
H *Main Gas Flue.*

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of heat has been obtained from the heated regenerators through which they have passed being added to that of the heat of combustion. This economy is produced by means of the regenerators in which is stored up and restored the heat which cannot be immediately utilized. The regenerators are made of such a capacity and so arranged as to allow the heat to pass away by the stack at the minimum temperature which establishes a draught sufficient to prevent an outward pressure on the furnace from extending to a back pressure in the valves, that is, a draught sufficient to draw the products of combustion forward after leaving the top of the regenerators.

The amount of brickwork required in the regenerators to absorb the waste heat of a given furnace is a matter of simple calculation. The products of the complete combustion of 1 lb. of coal have a capacity for heat equal to that of nearly 17 pounds of firebrick,* and (in reversing every hour) 17 pounds of regenerator brickwork at each end of the furnace per pound of coal burned in the gas producer per hour would be theoretically sufficient to absorb the waste heat, if the whole mass of the regenerator were uniformly heated at each reversal to the full temperature of the flame, and then completely cooled by the gases coming in; but in practice by far the larger part of the depth of regenerator chequer-work is required to effect the gradual cooling of the products of combustion, and only a small portion near the top, perhaps a fourth of the whole mass, is heated uniformly to the full temperature of the flame; the heat of the lower portion decreasing gradually downwards nearly to the bottom. Three or four times as much brickwork is thus required in the regenerators, as is equal in capacity for heat to the products of combustion.

From experiments made by C. W. Siemens on his regenerative steam engine, and given in his paper "On the Conversion of Heat into Mechanical Effect," vol. xii. of the "Proceedings of the Institution of Civil Engineers," it was found that one-twentieth of the heat was wasted in the regenerators. From experiments made by Professor Norton on the screw-steamer *Ericsson*, the waste in the shorter regenerators used in its engines appears to be about one-tenth of the heat stored. The loss in a regenerator depends, first, upon the amount of surface relatively to the amount of heat to be transmitted; and secondly, on the loss by conduction and radiation. Taking into consideration the notably too small surface of the regeneratiors of the engines of the *Ericsson*, and the incidental loss by radiation from the exposed surface of the heated cylinder, the above factor of one-tenth is evidently too great. On the other hand, one-twentieth, which was the result of careful experiments in which the maximum efficiency was obtained, would be too small an allowance to make in actual practice, where loss might be occasioned by the reversing valves not being turned at the right moment, and one-fifteenth will be employed in the following calculation.

In order to calculate at any moment the efficiency of a heat engine (and there is no reason why a metallurgical furnace should not be treated in the same manner), all that it is requisite to know is the maximum temperature and the range of temperature. The minimum temperature is easily obtainable, and the maximum temperature may also be obtained by experiment. It has been so obtained with the electrical pyrometer already described, and has been found to be 1611° C., or adding 274°, the distance of the zero Centigrade from the absolute zero of temperature, 1885° absolute. The temperature at which the waste gases leave the chimney is never above 170° C., or 444° absolute. The range of temperature is 1885° — 444° = 1441°, and the ratio of this to 1885 + one-fifteenth for loss in the regenerators is $\frac{1441}{1885 + 141} = \frac{1441}{2026} = 71$ per cent. of efficiency. In the steel melting furnace, and allowing the maximum temperature to be 2000° C., equivalent to 2274° absolute, the range of temperature is 2274° — 444° = 1830°, and the efficiency $\frac{1830}{2274 + 169} = \frac{1830}{2443} = 75$ per cent. of efficiency.

The regenerative furnace must be considered as a furnace containing at any moment a certain quantity of heat at a certain temperature, in connection with two pairs of regenerators, the brickwork of which also contains a certain amount of heat between certain limits of temperature.

In working a furnace in the most economical manner, the total quantity of heat in the two pairs of regenerators is always constant, and it is assumed that the total quantity of heat taken up at any moment by the entering gas and air, from one pair of regenerators, is restored by the products of combustion to the other pair.

In a paper by W. C. Roberts, read before the Royal Society on the 18th March, 1875, the

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* Taking the analysis by Vaux of the celebrated ten-yard coal of South Staffordshire (Watts' Dictionary of Chemistry, i. 1081), the exact calculation is as follows:—

Composition of the coal.			Oxygen required.
Carbon, ...	·7857	$\times \frac{8}{3} =$	2·0952
Hydrogen, ...	·0529	$\times 8 =$	0·4232
Sulphur, ...	·0039	$\times 1 =$	0·0039
Nitrogen, ...	·0184		2·5223
Oxygen, ...	1288	........less.....	0·1288
Ash, ...	·0103		
		net oxygen required	2·3935
	1·0000	20 per cent. excess	0·4787
		Total oxygen, ...	2 8721

Corresponding nitrogen, ...9·616
Nitrogen in the fuel, ... ·018
Total nitrogen, ... 9·634

Gases produced from 1 lb. of coal.		Specific heats.	Equivalent weight of water.
Carbonic acid,	= 2·881	·217	·625
Water (Steam),	= 0·476	·480	·228
Sulphurous acid,	= 0·004	·154	·001
Oxygen in excess,	= 0·479	·218	·104
Nitrogen,	= 9·634	·244	2·350

Total equivalent weight of water, ...3·308
" " firebrick (sp. heat = 0·2) 16·540

mean specific heat of iron between 0° and 1040° C. is given at ·15693. Weinhold gives ·1567 as the mean specific heat of wrought iron between 0° and 900° C. ("Pogg. Ann." vol. cxlix. p. 214). Between 0° and 100° C. it is ·1098, according to the experiments of Dulong and Petit, and between 0° and 300° C. it is ·1218; and assuming it to increase in the same ratio with increased temperature, the mean specific heat of iron between 0° and 2000° C. will be ·21. The specific heat of steel at lower temperatures is to that of iron as 1·044 is to 1; and assuming the same ratio to exist at the higher temperatures, the mean specific heat of steel between 0° and 2000° C., its point of fusion, will be ·2192. In order to raise 1 lb. of steel to the temperature of fusion, it will require $1 \times 2000 \times \cdot 2192 = 438{\cdot}4$ Centigrade gramme thermal units. The latent heat of fusion of steel is not known, but as that of tin, whose point of fusion is 232° C., is 280 units, it may be assumed to be equal to at least 1000 units, which, added to 438, gives 1438 units as the number required to fuse 1 lb. of steel. For all operations connected with melting 1 lb. of steel in crucibles, the regenerative gas furnace requires, according to the result of experience, $1\frac{1}{2}$ lbs. of common coal, or say 1 lb. of carbon. In the old process formerly carried on at Sheffield, double this quantity was required. From these figures it appears that the regenerative gas furnace produces, in manufactured steel, about 18 per cent. of the theoretical equivalent of the fuel, and the Sheffield coke holes about 9 per cent.

The regenerative gas furnace can be applied to any art or manufacture in which a large supply of heat at a high temperature is required, or where it is important that the nature of the heat should be under control. Its principal applications hitherto have been to the manufacture of iron, steel, and glass.

The production of wrought iron is a branch of manufacture to which the furnace has been applied. We must refer here, for the proper consideration of this application, to a paper read in 1868 by C. W. Siemens before the British Association at Norwich. He then combated, both by experiment and argument, the popular belief that "the oxygen acting upon the silicon and carbon of the metal is derived from the flame, which should therefore contain an excess of oxygen:" 10 cwts. of Acadian pig metal and 1 cwt. of broken glass were charged upon the bed of a regenerative gas furnace, the bed being formed of pure silicious sand. The silicon and carbon gradually diminished, thus proving that "no silicon is taken up by fluid cast metal in contact with silica or silicates." "At the end of six hours the metal was tapped, and the silicon and carbon had been almost entirely removed from the pig metal by mere contact with metallic oxide under a protecting glass cover." "I then stated that the removal of the silicon and carbon from the pig iron, in the ordinary puddling or boiling process, is due entirely to the action of the fluid oxide of iron present, and that an equivalent amount of metallic iron is reduced and added to the bath." In an ordinary puddling furnace, in which the heat required for performing the operation is obtained by burning a portion of the iron as fuel, the amount which should be gained is not only lost, but other iron besides. This waste does not occur in the regenerative gas furnace, both because the flame is of a neutral nature, and because the heat is obtained by the heating and combustion of the gas and air employed. Another advantage to the puddling process gained by the application of heat of high intensity, is the perfect fluidity insured, causing the separation of sulphur and phosphorus by liquation, as suggested by Percy; *i.e.*, the crystals of metallic iron exclude foreign substances when the metal comes to nature, in the same way as ice does salt.

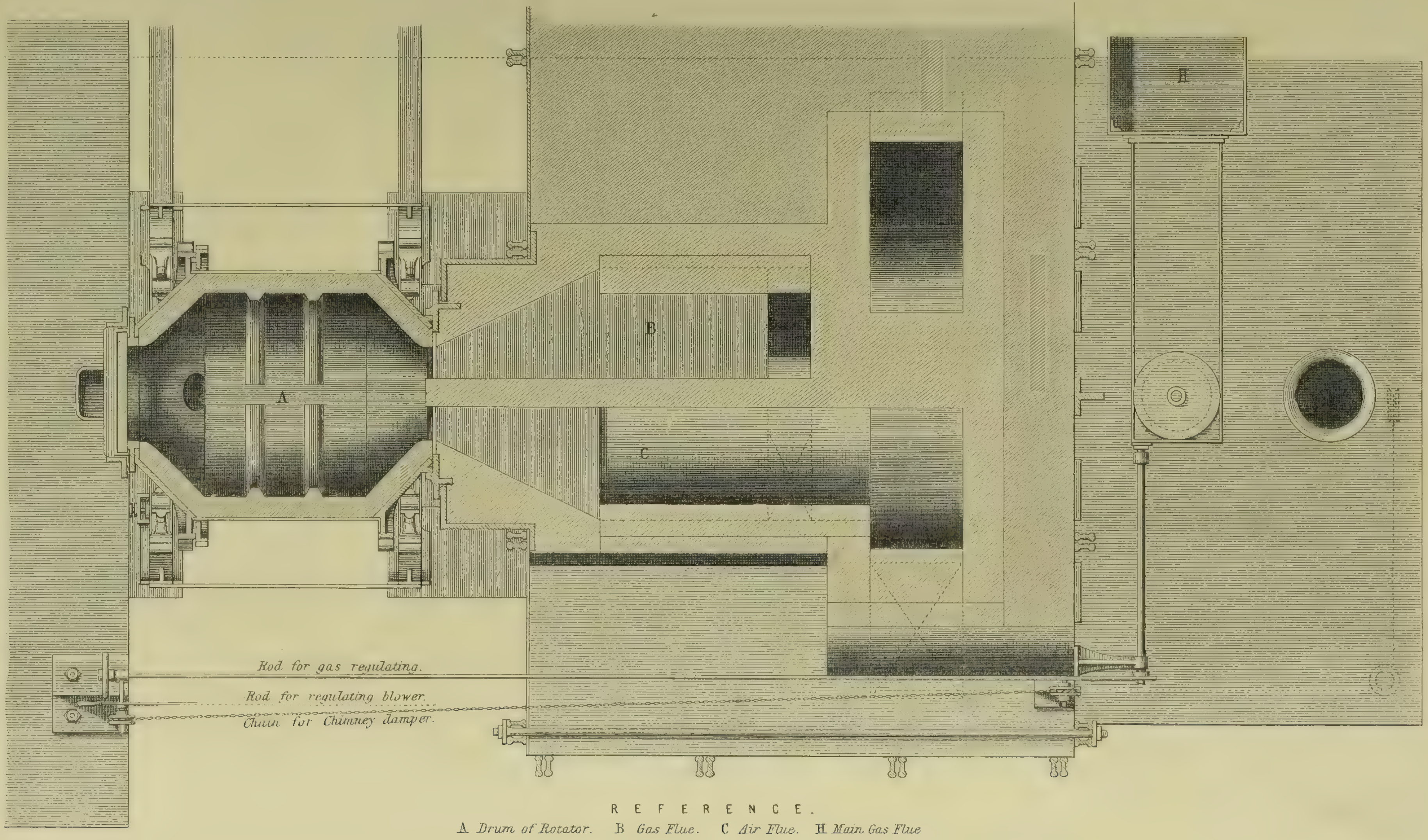
The bed of the furnace for this application is of the ordinary construction; it is provided with water bridges at the ends to protect the "fettling" (or oxide of iron used for lining the furnace) from being melted; a heating chamber is placed at each end of the furnace, in which the charge of pig iron may be heated to redness before being introduced into the puddling chamber.

The regenerative gas furnace is employed as a reheating or mill furnace. Its economy in this application is accounted for by the perfect control over the flame, its gentleness and purity, and the absence of dust and of cutting draughts.

The following description of the rotatory furnace, in which wrought iron is manufactured direct from the ore, is reprinted from a lecture delivered by C. W. Siemens before the Chemical Society, March 20, 1873, and gives, besides a description of the furnace, a theoretical evaluation of the minimum of fuel with which a certain weight of steel can be produced.

Plates II. and III. represent the complete rotatory furnace, such as is now in use. It consists of a set of four regenerators of the usual construction with reversing valves and gas producers, which latter are not shown. The rotative chamber is constructed of iron, and rests upon four anti-friction rollers. Wheel gearing is applied by which either a very slow rotative velocity of from four to five revolutions per hour can be imparted to the chamber, or a more rapid velocity of about 60 to 80 revolutions per hour. The chamber is about 7 feet 6 inches in diameter and 9 feet long, and is provided with a Bauxite lining about 7 inches thick. A tap-hole is on the working side for discharging the slag into the cave below, where it is received in vessels mounted on wheels. At the two extremities of the cylindrical rotative chamber with its truncated ends, are large orifices, one of which, on the side of the regenerators, serves for the introduction of the heated gas and air as well as for the exit of the products of combustion, and the other facing the working platform is closed by a stationary door hung before it in the usual manner. Although the passage for the introduction of the gases in combustion is separated only by a vertical partition wall from the passage through which the products of combustion are led away, the chamber is heated very perfectly, care only being taken that the gases enter the chamber with a certain velocity, which sends

SECTIONAL PLAN OF SIEMENS' ROTATORY FURNACE FOR THE DIRECT MANUFACTURE OF IRON & STEEL.



REFERENCE.

A. Drum of Rotator. B Gas Flue. C Air Flue. H Main Gas Flue

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them forward towards the door and makes them reach the exit passage only after having traversed the rotative chamber to and fro.

This rotative furnace is worked as follows:—

The ore to be smelted is broken up into fragments not exceeding the size of peas or beans; to it is added lime or other fluxing material in such a proportion that the gangue contained in the ore and flux combines with only a little protoxide of iron into basic and fluid slag. With hæmatite or siliceous ore, it is preferable to add alumina in the shape of aluminous iron ore; manganiferous iron ore may also be added with advantage. A charge of say 20 cwts. of ore is put into the furnace when fully heated, while it is slowly revolving. In about forty minutes this charge of ore and fluxing material will have been heated to bright redness, and at this time from 5 cwts. to 6 cwts. of small coal of uniform size (not larger than nuts) are added to the charge, whilst the rotative velocity is increased for a short time in order to accelerate the mixture of coal and ore. A rapid reaction is the result: the peroxide of iron being reduced to magnetic oxide begins to fuse, and at the same time metallic iron is precipitated by each piece of carbon, while the fluxing materials form a fluid slag with the siliceous gangue of the ore. The slow rotative action is again resorted to, whereby the mass is turned over and over, presenting continually new surfaces to the heated lining and to the flame within the rotator.

During the time of this reaction carbonic oxide gas is evolved from the mixture of ore and carbon, and heated air only is introduced from the regenerator, to effect its combustion within the rotating chamber. The gas from the gas-producers is entirely, or almost entirely, shut off during this portion of the process. When the reduction of the iron ore is thus nearly completed, the rotator is stopped in the proper position for tapping off the fluid cinder; after this the quick speed is imparted to the rotator, whereby the loose masses of iron contained in it are rapidly collected into two or three metallic balls. These are taken out and shingled in the usual way of consolidating puddled balls; the furnace is tapped again, and is ready to receive another charge of ore. The time occupied in working one charge rarely exceeds two hours; and supposing that 10 cwts. of metallic iron is got out per charge, the apparatus is capable of turning out at least 5 tons of puddled bar per twenty-four hours. If anthracite or hard coke is available for effecting the reduction of the ore, it should be crushed much finer than when coal or brown coal is used, the idea being that each particle of the reducing agent should be fully consumed during the period of chemical reaction. If wood is used, it has to be charged for the same reason in still larger pieces.

If it is not intended to make iron, but cast steel, the balls may be transferred from the rotator to the bath of a steel-melting furnace in their heated condition, and without subjecting them to previous consolidation under a hammer or shingling machine.

It is feasible, however, to push the operation within the rotator to the point of obtaining cast steel. If this is intended, the relative amount of carbonaceous matter is somewhat increased in the first instance, so that the ball, if shingled, would be of the nature of puddled steel, or contain even some carbon mechanically inclosed.

If now, after removing the cinder by tapping, from 10 to 15 per cent. of ferro-manganese or spiegeleisen is thrown in, and the heat within the rotator is rapidly raised by urging the influx of heated gas and air from the regenerator, the metallic balls will soon be seen to diminish, and presently a metallic bath only will be found in the furnace, which may be tapped into moulds and hammered and rolled into steel blooms or bars in the usual manner.

In comparing upon theoretical grounds this method of producing metallic iron with the operation of the blast furnace, it will be at once perceived that, whereas in the blast furnace the products of combustion consist chiefly of carbonic oxide, and issue from the top of the furnace at a temperature exceeding 350° C., the result of combustion in the rotative furnace is carbonic acid, which issues from the regenerative furnace into the chimney at a temperature rarely exceeding 170° C. This proves at once a great possible saving of fuel in favour of the proposed method, and to this saving has to be added the fuel required for converting pig metal into wrought iron by the puddling process.

It may however be asked, why the rotating furnace should admit of the complete combustion of carbon, whereas in the blast furnace such complete combustion is, as is well known, not possible, because each atom of carbonic acid formed would immediately split up into two atoms of carbonic oxide, by taking up another equivalent of carbon from the coke present. The following explanation will serve to elucidate this point:—

In the rotative furnace streams of carbonic oxide are set up within the mass under reaction; and this carbonic oxide on reaching the surface meets the current of intensely heated air proceeding from the regenerators, and completes with it perfect combustion within the free space of the chamber. The carbonic acid thus generated comes in no further contact with carbon or metal, consequently it cannot split up, but is drawn away unchanged into the chimney, while the evolved heat is taken up by the sides of the chamber and transmitted by reverberation and conduction to the mixture of ore, fluxes, and coal.

In this process we have therefore to accomplish two things, viz., the deoxidation of the ore and the fusion of the earthy matter mixed with it. If we take, say, hæmatite ore, consisting of peroxide of iron with 10 per cent. of silica, we shall determine the quantity of carbon necessary for its reduction from the formula:—

$$Fe_2O_3 + 3C = 2Fe + 3CO;$$

and according to which the consumption of carbon (taking its atomic weight at 12 and that of iron at

56) amounts to $\frac{3 \times 12}{2 \times 56} = \cdot 32$ lbs. per lb. of iron reduced.

The heat absorbed in this reaction amounts, according to DEBUS, to 892 units* per lb. of iron produced, but on the other hand the further combustion of ·32 lb. of carbon from the condition of carbonic oxide to carbonic acid (CO to CO_2), by means of the free oxygen introduced into the rotative chamber from the regenerator yields $\cdot 32 \times 5600 = 1792$ units of heat, leaving $1792 - 892 = 900$ units available for heating the materials and for melting the slag.

The quantity of materials to be heated per lb. of iron produced would amount to

Ore,	1·59
Lime or other fluxing materials,	·16
Total,	1·75

And taking the specific heat of Fe_2O_3 at ·154, as determined by HERMAN KOPP, and the temperature to which the materials have to be raised at 1500° C., the heat required for this purpose would not exceed $1\cdot 75 \times \cdot 154 \times 1500 = 404\cdot 25$ units. To this consumption would have to be added the latent heat absorbed in liquefying the slag. The slag would amount to ·16 lb. silica + ·16 lb. lime = ·32 lb. per lb. of iron produced; and although we have no precise data from which we could ascertain the latent heat absorbed in liquefaction, we can hardly estimate it at more than 150 units per lb., or at $\cdot 32 \times 150 = 48$ units, which, with the above 404·25, makes 452·25 units, whereas 900 heat-units are available, as resulting from the calculation above given; proving that ·32 lb. of pure carbon would, theoretically speaking, amply suffice to produce 1 lb. of puddled bar from ordinary hæmatite ore, without counting, however, losses of heat by radiation and from other causes.

In the production of cast steel, three operations are essentially involved, viz., the deoxidation of the iron, the fusion of the slags, and the fusion of the metal itself with such proportion of carbon and manganese as is necessary to constitute steel of the temper required.

The theoretical quantity of fuel required to accomplish these operations would exceed that of making wrought iron by the fusion of heated metal, which may be estimated at, say, 1000 units, or at $\frac{1000}{8000} = \cdot 125$ lb. of carbon per lb. of steel produced, which have to be added to the ·32 lb. used in reduction.

In fine, a ton of iron ought to be producible from hæmatite ore with 6·4 cwts. of carbonaceous matter, or say 8 cwts. of common coal, and a ton of cast steel with 8·90 cwts. of carbon, or say 11 cwts. of coal. In giving these figures I do not wish to imply that they will ever be completely realised, but I maintain that, in all our operations, we should fix our eyes upon the ultimate result which theory indicates, which, owing to the imperfect means at our command, we shall never completely reach, but which we should constantly endeavour to approach.

In taking incidental losses by radiation through imperfect combustion and through imperfect absorption of heat into account, we find that the actual consumption exceeds the theoretical limits about three times, or that a ton of iron can practically be produced with a consumption of 25 cwts. of coal, and a ton of cast steel with 40 cwts. of coal, which consumption represents a great reduction as compared with other methods of production.

One of the first applications of the regenerative gas furnace was to the manufacture of steel in crucibles. The melting chamber is constructed in the form of a long trench, wider below than above. The sides are arched horizontally and vertically, and strengthened by cross walls at intervals. The pots are set in a double row along the centre, and the flame passes across, the gas and air from the regenerators being introduced alternately from one side and from the other opposite each pair of pots, and impinges upon the foot of the crucibles. There are loose fire-brick covers above for the removal of the pots. These stand on a bed of fine coke-dust, which burns slowly and does not cake.

But the most extensive applications of the furnaces have been to the manufacture of cast steel and glass on the open hearth. To the former of these reference will now be made, whilst the other will be described under the article GLASS. The furnace employed for the manufacture of cast steel on the open hearth (see Plate IV.) is similar to the puddling furnace: the flame passes from end to end, the bed is supported on iron plates, and a current of air passes underneath to keep it cool. The upper part of the furnace is built entirely of Dinas brick, and the bed is formed of silicious sand. In the front are doors for repairing the furnace, and through which heavy scraps can be charged in. At the back are sloping shoots for charging old rails, &c., and beneath these are openings for charging the pig iron.

The bed is made of sand introduced in layers of an inch thick, the heat being sufficient to fuse the surface of the layer. The bed of the bath must be of the form of a hollow basin, being deepest near the tap hole. In tapping, the loose sand near the tap hole is removed, and the surface of the hard crust being pierced, the fluid metal runs from the hottest and deepest portion of the bath.

When the hard bottom has been prepared the furnace is raised to a white heat, and is ready to receive the materials to be heated. If the furnace is constructed to receive a 3-ton charge, 6 cwts. of grey pig metal are introduced into the furnace, and old iron and steel rails, or bar iron cut into lengths of about 6 feet, are introduced through the slanting hoppers at the back, so that their ends rest on the bath. As these dissolve they descend, and in order to maintain the high temperature, notwithstanding the introduction of fresh charges, a portion of the flame is arranged to escape and heat the descending

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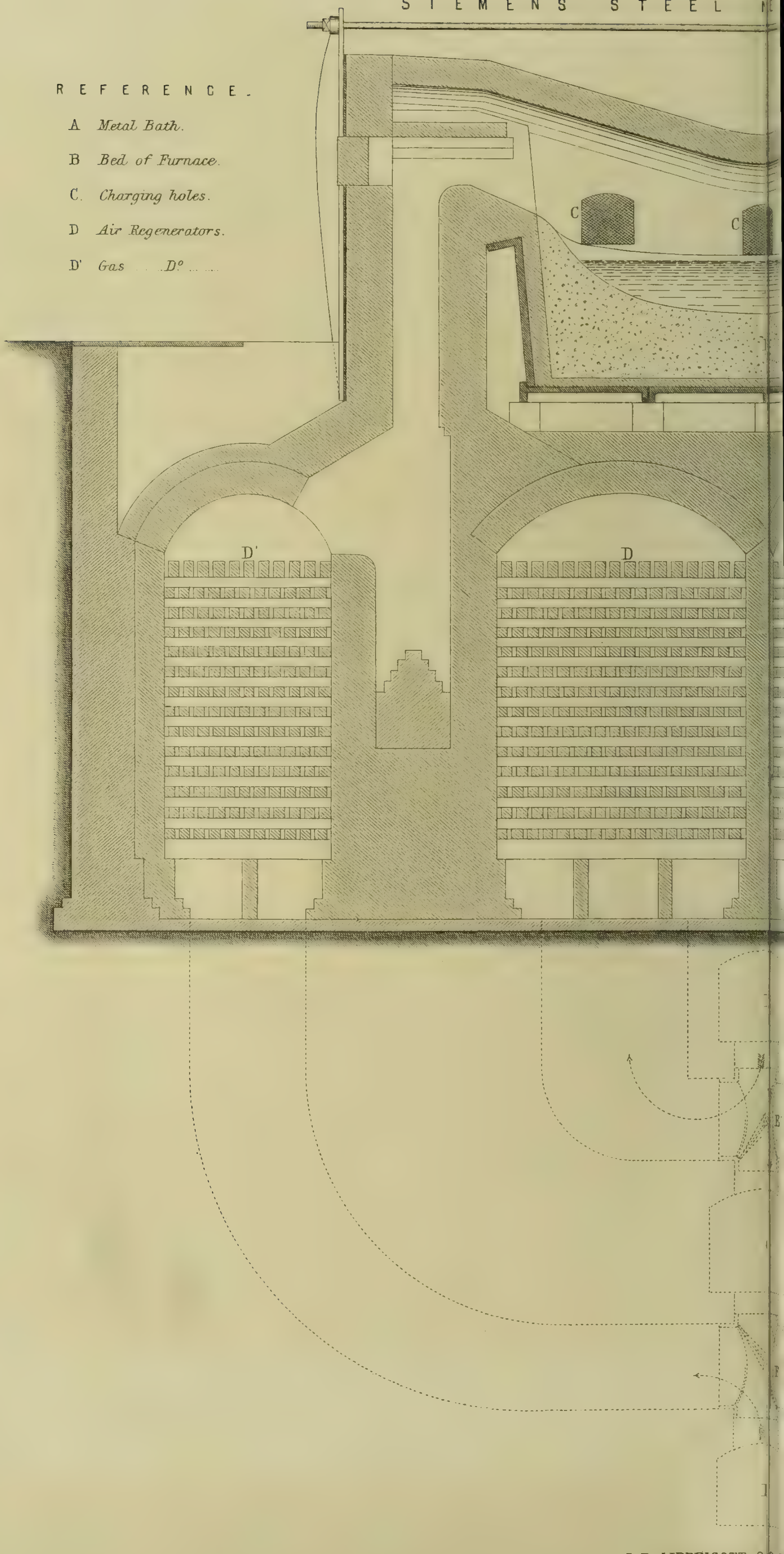
* A. W. Williamson gives 885·3 units as the result of his calculation, which two figures agree sufficiently for my present purpose.

FU

SIEMENS' STEEL

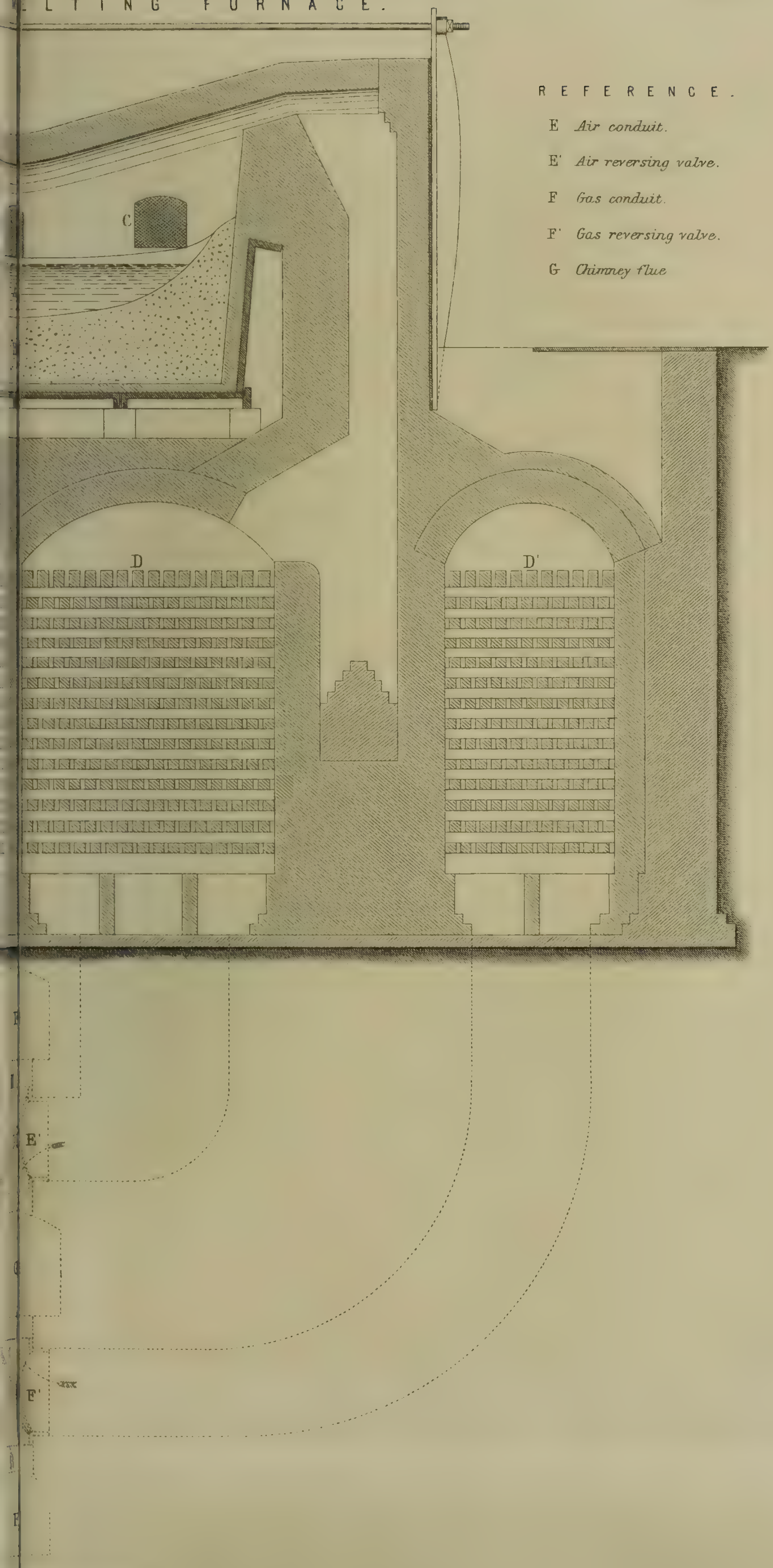
REFERENCE.

A *Metal Bath.*
B *Bed of Furnace.*
C. *Charging holes.*
D *Air Regenerators.*
D' *Gas ... D°....*



J. B. LIPPINCOTT &

ELTING FURNACE.



REFERENCE.

E	*Air conduit.*
E'	*Air reversing valve.*
F	*Gas conduit.*
F'	*Gas reversing valve.*
G	*Chimney flue*

T & PHILADELPHIA.

bars. The process is continuous, and in this way by the end of three or four hours 3 tons of metal charged will have been rendered fluid. The temper and quality are then tested, and if the fracture is bright and crystalline, and the metal tough and malleable, 8 to 9 per cent. of spiegeleisen, containing 9 per cent. of manganese, is charged through the side openings and allowed to unite with the bath, which is then fit for tapping.

The temper is determined by the amount of carbon introduced with the spiegeleisen. The fluidity of the bath allows of the introduction of litharge in connection with alkaline nitrates, chlorates, &c., which combine with sulphur, phosphorus, silicon, and arsenic.

For some time the furnace was applied to the reduction of iron oxides by feeding them with carbonaceous material into a reverberatory furnace, through inverted fire-clay hoppers, the oxides being reduced to spongy metal, and that fused on the open hearth. But both this method and another in which the spongy iron was first formed in a rotatory furnace and then dropped into the bath of a steel-melting furnace, failed through the spongy iron absorbing sulphur from the heating gases, and also from its floating on the liquid bath without being absorbed into it.

On the other hand, SIEMENS had observed that in melting iron ores no sulphur was absorbed from the flame; and it occurred to him that by melting ores mixed with fluxing materials in a furnace so arranged as to accomplish its fusion in a continuous manner and on a large scale, the fused ore might be acted upon by solid carbonaceous matter, so as to separate the metallic iron in a more compact form, while the earthy constituents of the ore would form a fusible slag with the fluxing material. Experiments proved that this reduction by precipitation of the iron could be accomplished only at an intense heat, exceeding the welding heat of iron, but that the iron so produced was almost chemically pure, although the ores and the fuel used might contain a very considerable percentage of sulphur and phosphorus.

The furnace used for carrying out this process of fusion and precipitation consists of a reverberatory gas furnace having two beds formed by the ore itself; on the upper bed a lake of fused ore is formed, which can be let off into the lower bed by piercing the intervening bank of unfused ore; the lower bed is divided into two compartments, used alternately, each provided with a working door. The dense carbonaceous material, such as anthracite or hard coke, to be used for the precipitation of the iron in the lower bed, is reduced to a state of powder and mixed with about an equal weight of pulverulent ore. This mixture is spread over the bottom surface of the working bed, and the fluid ore is let in upon it. By stirring with a rabble it is transformed into a pasty and foaming mass, which in the course of from forty to fifty minutes is shaped into a metallic ball in a bath of fluid cinder, which may be shingled in the usual manner, and formed into bar iron or transferred to the pig-iron bath of a steel-melting furnace, where it readily dissolves. The accomplishment of this process involves, however, a certain degree of manual labour and skill, as if it be carelessly conducted the yield of iron will be unsatisfactory; the analysis of the slags shows a variable percentage of iron amounting rarely to less than 15 per cent., but reaching occasionally up to 40 per cent.

Dr. SIEMENS says, with regard to the difficulty of obtaining refractory materials for the lining of the furnaces:—Considerable difficulty was experienced to find a material to resist the excessive heat necessary for carrying out this process; ordinary Dinas bricks, which are considered the most refractory material in general use, would be rapidly melted; but a brick specially prepared by crushing pure quartz rock, and mixing it with not more than 2 per cent. of quicklime to give cohesion, answers well. The hearth of the furnace is made of white sand with a small admixture of more fusible fine sand, which mixture sets exceedingly hard at a steel-melting heat, and possesses the advantage of combining into a solid mass with fresh materials introduced between the charges to make up for wear and tear. The hearth and the furnace roof, if of the materials just specified, are very little attacked when the SIEMENS-MARTIN or scrap process is used, although the heat must be sufficient to maintain wrought iron containing only a trace of carbon in a perfectly fluid condition. If pig metal and ore (previously fused with the necessary amount of flux) are used, the furnace also stands well, but the use of raw ore entails the disadvantage of a more rapid destruction of the furnace; even magnetic oxide of the purest description necessitates the addition of raw lime for the formation of a fusible slag, and the dust rising from the lime and through the decrepitation of the ore causes the silica bricks to melt away rapidly, so that after perhaps two months' usage the 9-inch arch of the furnace is reduced to the thickness of from 1 to 2 inches. It is evident that silica is chemically speaking an objectionable material to be used in the construction of these furnaces, because it prevents the formation of basic slags, and that a furnace bed constructed of pure alumina or lime would be preferable. My friend M. LE CHATELIER, Inspecteur-Général des Mines, whose valuable labours for the advancement of iron metallurgy are well known, suggested to me years ago the use of Bauxite (from Baux in France, where it was first discovered), a mineral consisting chiefly of alumina, for making the furnace-bed; but I was not able to succeed with this owing to the great contraction of the mass when intensely heated, and non-cohesion with the same material introduced for the purpose of repair. In attempting to construct the sides and roof of the furnace of Bauxite bricks, these were not found to be equal in heat-resisting power to silica bricks, which latter are indeed unobjectionable, except when raw ore and limestone are used.

A series of experiments to form solid lumps by using different binding materials have shown that 3 per cent. of argillaceous clay suffice to bind the Bauxite powder previously calcined. To this mixture about 6 per cent. of plumbago powder is added, which renders the mass practically infusible, because it reduces the peroxide of iron contained in the Bauxite to the metallic state. Instead of plastic clay as the binding agent, waterglass or silicate of soda may be used, which has the advantage of setting into a hard mass at such a comparatively low temperature as not to consume the plumbago in the act of burning the brick. When the lining is completed the interior of the bricks is preserved against oxidation by fluid cinder, added to bind them together, which also prevents contact with the flame. A Bauxite lining of this description resists both heat and fluid cinder in a very remarkable degree. It is also important to observe that Bauxite, when exposed to intense heat, is converted into a solid mass of emery of such extreme hardness, that it can hardly be touched by steel tools, and is capable of resisting mechanical as well as the calorific and chemical actions to which it is exposed. The Bauxite so used was composed of—

Alumina,	53·62 per cent.
Peroxide of iron,	42·26 "
Silica,	4·12 "

GAS.—*Gas*, French; *gaz*, German.—The term gas, as referring to aeriform bodies, is one of comparatively modern date. It is said to have been introduced by Van Helmont in the seventeenth century. In his writings perhaps the earliest mention is to be found of aeriform substances differing in character from atmospheric air, and it would appear that he carried out some experiments upon the weight and elasticity of air, and also upon its relation to temperature and pressure. Van Helmont at the same time draws a distinction between permanent gases and those which are evidently the vapours of volatile liquids; and he recognized the gas which is known to us now as carbonic acid, as being amongst the products of the combustion of carbonaceous fuel.

It was not, however, until after the proof of the ponderability of air by Torricelli in 1643, and the experiments of Otto Guericke about 1650, whereby the absolute weight of a given volume of air was determined, that the fact of the materiality of gaseous matter was fully established; and this knowledge leading to the study of other aeriform bodies differing from air in character and properties, the term gas came into use to denote generally a body of a gaseous or aeriform nature.

The first of these gases which was carefully studied was the compound gas carbonic acid, which, as before mentioned, was suspected to exist amongst the products of combustion by Van Helmont; but it remained for Black in 1756 to demonstrate by his experiments on the source of the causticity of the alkalies, and of the alkaline earths, the real character and nature of this body, which he called *fixed air*, and which he obtained variously by heating chalk, limestone, or carbonate of magnesia.

A little subsequently to this, in 1766, Cavendish, in his "Experiments on Factitious Air," detailed a number of his observations upon carbonic acid gas or fixed air, and also upon another gas, hydrogen, or as he called it, "inflammable air." Cavendish also obtained this air by the action of certain acids upon some of the metals, and he carefully investigated its properties, determining at the same time its specific gravity, which showed it to be the lightest of all hitherto known material substances. It was during the progress of these experiments that Cavendish was led to the important discovery of the compound nature of water.

The fact of the existence of aeriform bodies other than atmospheric air having been thus clearly established, and the character and properties of two of these bodies (fixed air or carbonic acid, and inflammable air or hydrogen) having been carefully examined, a great incentive was given to this kind of investigation, and many phenomena which had been previously observed, but which had been considered of no special importance, were made the subject of experiment.

Thus, in 1772, Rutherford showed by some experiments on respiration, that the atmosphere contained a gas (nitrogen) which could not support combustion or life; and that the reason why air became soon vitiated by such respiration was not altogether due to the products formed, but that it was the effect of this gas nitrogen, or as he then called it "azote," occurring naturally as a constituent of the atmosphere.

In 1772-73 Priestley published a work, "Observations on Different Kinds of Air," and by a number of experiments laid the foundation for the very important discovery of oxygen, which he made in 1774. In 1771 Priestley had observed that growing plants in sunlight in presence of carbonic acid altered the character of this gas, so that after a time its power of putting out a light was lost, and it became capable of supporting both combustion and animal life. Neither the exact nature of this change nor the character of the residual gas was at the time clearly made out; but in 1774, following closely upon the experiments of Lavoisier and Bayen, Priestley obtained oxygen gas by heating in a closed tube over mercury a small quantity of mercuric oxide. This gas, to which the term "vital air" was shortly afterwards given, was submitted to careful study, and it may be said that it was from this date that pneumatic chemistry became an important branch of the science. Priestley's name as a discoverer is also associated with other gases, he having determined the existence and the nature of hydrochloric acid, ammonia, sulphurous acid, and nitrous oxide gases. Lavoisier, in the same year in which oxygen was discovered, came to the conclusion that this gas was identical with the vital constituent contained in common air, which belief was afterwards confirmed by Cavendish by a careful analysis; and in his "Experiments on Air," published in 1785, its composition by weight and volume as regards oxygen and nitrogen was definitely established. During the year 1774, which was a very important one in the history of gaseous substances, the German chemist Scheele made the discovery of what he termed "dephlogisticated muriatic acid," now known as chlorine gas. For a considerable time this gas was regarded as a compound of oxygen with muriatic acid; but in a paper by Sir H. Davy, published in the "Philosophical Transactions" for 1811, the elementary nature of chlorine was established.

Of the other compound gases which were discovered or recognized at the close of the last century, sulphurous acid gas was suspected to exist by Stahl, was prepared and examined by Scheele, and also by Priestley in 1774, and was afterwards very completely investigated by Berthollet in 1782. Sulphuretted hydrogen was discovered by Scheele in 1777. Ammonia gas was prepared by Priestley, who called it "alkaline air," in 1774, and examined by Berthollet in 1785. Carbonic oxide was discovered and studied about the same time by Lassonne and Priestley. Olefiant gas, or heavy carburetted hydrogen, was prepared by the Dutch chemists, Bondt and Dieman, in 1796, and at the beginning of the present century the fire damp, mine or marsh gas, or light carburetted hydrogen, was recognized and carefully studied by Sir H. Davy.

Thus it will be seen that, in a space of scarcely thirty years, a large number of gaseous bodies had not only been discovered, but the foundation of an entirely new branch of chemical and physical science had been laid.

In 1823 Faraday determined a gas to be the vapour of a volatile liquid, existing at a temperature considerably above the boiling point of the liquid; and that the condensing points of different gases are merely the boiling points of the liquids producing them. Chlorine was the first gas he liquefied.

Theory of Gaseous Matter.—From considerable evidence it is conceived that the constituent molecules of matter in any state are not at rest, but have a definite and peculiar motion or vibration of their own. In the solid and liquid states of matter this motion is more or less controlled by the presence of the force of cohesion. In the solid state the molecules vibrate about certain fixed positions, which they cannot leave, and which movement therefore in nowise interferes with the rigidity or shape of the body. The exact nature of this motion has not yet been determined; it may either be a motion of the atoms constituting the molecules, or the molecules themselves may vibrate as a whole; but under any circumstances it is always possible by external means to alter the position of the fixed points of equilibrium about which such motion occurs, and this may be done either temporarily or permanently.

In the liquid state these fixed points of equilibrium are abolished, and the molecules may move into any positions, or may rotate about themselves. There is still, however, a regulating power present which prevents the molecules from becoming permanently dissociated from each other, and which retains them within certain limits, so that in liquids there is no tendency of the molecules to fly asunder, and consequently no outward pressure.

In the gaseous state the molecules are altogether freed from their mutual attraction, and hence, if any motion be imparted to them, they will follow the ordinary laws of bodies in motion, and will move through space with a definite velocity; if meeting any impediments in the shape of other molecules, in whatever state of aggregation, the direction of motion will be changed, and a certain equivalent of motion will be imparted to the obstacle. These molecules, also, if striking against any surface, will exert a certain pressure upon that surface, which pressure, under certain conditions, may readily be calculated. It will also follow how that, when in the liquid state, the molecules have acquired a certain motion, such motion will be regulated and controlled by the presence of other molecules immediately surrounding them; this, however, ceases to be the case at the surface of a liquid, for at this point the molecules have not this resistance; and if their motion be of sufficient magnitude it will propel them forward into space to such a distance that the effect of their mutual attraction will be entirely overcome, and they will exist under the same conditions as molecules in the gaseous state. In this manner the formation of vapours and gases from liquids is explained.

The absolute rate of motion of the molecules of various gases may be calculated with accuracy. Thus, if a flexible vessel of known cubical capacity be filled with a gas the density of which is known, and the vessel be exposed to a fixed external pressure, it can then be calculated what velocity the molecules of the gas in the interior must have to balance such a known external pressure. In this manner Clausius in 1857 calculated the velocities of the molecules of the following gases at 0° C.:—

Oxygen = 1514 feet per second.
Nitrogen = 1616 " "
Hydrogen = 6050 " "

The relation of heat to this hypothesis, concerning the physical state of matter, is recognized at once. If heat be imparted to a body in either state of aggregation, the motion of the molecules is thereby accelerated until the limit of such motion is reached, which allows the body to remain in any particular state of aggregation, and when, consequently, a further increase will cause the passage of the body into another form. Heat being still imparted to a body after it has assumed the gaseous state, will increase the velocity of the motion of the molecules, and will consequently, in a closed vessel, cause them to resist a greater pressure, or, under the same pressure, will resist that pressure over a greater area; hence follows the phenomenon of the expansion of gases by heat.

A perfect gas would be defined as possessing the condition of perfect fluid elasticity, and presenting, under a constant pressure, a uniform rate of expansion for equal increments of heat. But this theoretical definition is never absolutely realized; for although a few gases are still spoken of as perfect, and are represented, therefore, as fulfilling the above definition, yet all analogy and previous experience would indicate that this statement will have to be modified.

The pressure which a given gas exerts upon the walls of the vessel which contains it will depend upon the volume which the gas occupies; and **Boyle** and **Marriott** discovered the fact, which is stated in the law which bears their name, "that at a constant temperature the volume which a gas occupies varies inversely as the pressure." For some time it was believed that this was rigorously true; but the later experiments of **Despretz**, **Dulong**, and **Arago** have shown that under extreme pressures no gas follows out absolutely this law—those gases which are known to become liquids under increased pressure deviating to a larger extent than others. A perfect gas should apparently follow this law with mathematical accuracy, hence it is concluded that all gases are but the vapours of liquids having exceeding low boiling points.

Absorption of Gases by Liquids and Solids.—It may be broadly stated that all liquid and solid substances can absorb a certain amount of matter in the gaseous state. Liquids, as a rule, absorb gases to a greater extent than solids, those solids which exhibit the greatest porosity, and expose the largest absorbing surface, being the most active. In the first place, the nature of the gas, and of the liquid or solid, influences the amount of the gas absorbed—those gases which unite with water to form compounds being absorbed in the largest quantity, thus:—

VOLUMES OF GAS ABSORBED BY ONE VOLUME OF WATER AT 0° C.

Hydrogen,.........	0·00193	Ammonia,......	1180·000
Oxygen,...........	0·04114	Sulphurous acid...	68·61
Nitrogen,..........	0·02035	Hydrochloric acid,	490·0
Carbonic oxide,....	0·03287	Sulphuretted hydrogen,......	4·3706
Nitrous oxide,......	1·3052		
Carbonic acid,......	1·7967		

Secondly, the volume of the gas absorbed by a liquid is found to be the same at all pressures; or, in other words, the weight of the gas absorbed is directly as the pressure. The relation between the amounts of gas absorbed at different temperatures cannot be expressed by any general law, it must in each case be determined by experiment. If two or more gases which do not act upon each other be placed in contact with a liquid, each separate gas will be absorbed as if it were the only gas present; but the coefficients of solubility for each gas differ for every liquid.

The solution of atmospheric air in water has an important bearing in the economy of nature, especially with regard to the existence of life in fresh and salt water.

Those gases which dissolve in water to the greatest extent are found also to be absorbed by solids in the greatest quantity. Of the solids which are most active in this direction, charcoal, platinum sponge, and some of the metals may be mentioned; the gases so absorbed appear to undergo a change in physical state, and must be supposed in many cases to become solid.

The following co-efficients of absorption were obtained by **Saussure**, the experiments being made with box-wood charcoal:—

VOLUMES OF GAS, AT 12° C. AND 724mm. PRESSURE, ABSORBED BY ONE VOLUME OF BOX-WOOD CHARCOAL.

	Vols.		Vols.
Ammonia,............	90	Olefiant,...........	35·0
Hydrochloric acid,......	85	Carbonic oxide,......	9·4
Sulphurous acid,........	65	Oxygen,............	9·4
Sulphuretted hydrogen,..	55	Nitrogen,...........	7·5
Nitrous oxide,.........	40	Hydrogen,..........	1·75
Carbonic acid,.........	35		

Diffusion of Gases.—Some phenomena, explainable by this property of gases, have been known for some considerable time. Thus **Priestley** observed that gases if passed through heated earthenware tubes escaped through the pores of the tube; and again, in 1825, **Döbereiner** noticed that hydrogen contained over water in a cracked glass jar escaped through the crack more rapidly than the air entered the jar, the level of the water being consequently raised on the inside. These, and other observations imperfectly understood at the time, have been made clear by the elaborate investigations of **Graham**.

All gases, whatever their density, that do not act chemically upon each other, if brought into contact will intimately mix and diffuse themselves until a perfectly uniform mixture be formed, when they will not again separate unless some special and extraneous means be adopted. It matters not how narrow the aperture may be through which the gases have access to each other, the only difference in effect will be that a longer time is required to obtain perfect mixture.

By means of tubes closed by porous material such as plaster, unglazed porcelain, graphite, &c., **Graham** was able to construct an apparatus which he termed a diffusiometer, and by means of which he was able to determine the rates at which various gases diffuse either into a vacuous space or into a space filled with another gas. The lighter the gas the more quickly will it diffuse, and thus hydrogen is found to have the greatest velocity of diffusion of any gas. Thus, in an experiment of **Graham's**, a cylinder filled with hydrogen and fitted with a cork and glass tube bent at right angles and communicating with the external air, was found to have lost 81·6 per cent. of the gas in four hours, while the same cylinder filled with carbonic acid lost only 31·6 per cent. By a large number of experiments **Graham** succeeded in establishing the law, "That the rates of diffusion of any two gases are inversely as the square roots of their specific gravities." This law, however, only holds good so long as the porous material through which the gases pass is exceedingly thin; if any considerable thickness be used, the gases have to pass through small but distinct tubes, in which case other actions than that of diffusion are to be taken into account. The following table gives the rates of diffusion of four principal gases:—

TABLE OF DIFFUSION.

	Density. Air = 1.	$\frac{1}{\sqrt{\text{Density.}}}$	Velocity of Diffusion. Air = 1.
Hydrogen,..........	0·0692	3·779	3·830
Nitrogen,............	0·9713	1·015	1·014
Oxygen,.............	1·1056	0·951	0·949
Carbonic acid,.........	1·5290	0·808	0·812

This diffusion of gases has considerable technical importance, as by its means the constant composition of the atmosphere is maintained; and recently PETTENKOFER has shown that diffusion of air largely takes place through the brick walls of houses, thereby constituting an important element in the matter of ventilation.

For further information upon this subject reference may be made to GRAHAM'S researches, published in the "Philosophical Transactions," and for a condensed account to be found in WATT'S "Dictionary of Chemistry."

Liquefaction and Solidification of Gases.—In the early part of this article the definition of a perfect gas was stated to be "matter possessing the condition of perfect fluid elasticity, and presenting under a constant pressure a uniform rate of expansion for equal increments of heat." This condition is, however, never rigidly fulfilled; analogy and experimental evidence would tend to show that all gases under certain conditions, attainable or not as the case may be, could be made to assume the liquid, and possibly the solid state. If the dynamical theory be accepted, it follows that the existence of gaseous matter depends upon a molecular movement of the particles of the gas; if this motion be retarded or arrested, the gas will change its physical state. There is in gaseous matter a large amount of latent heat, or heat which is not manifest as heat, but as molecular motion. There will consequently be a possibility of liquefying a gas in two ways, either by abstracting this equivalent of heat, which will cause the motion largely to cease, or by overcoming and neutralizing such motion by a superior force. In this manner a gas may be possibly liquefied by exposing it to extreme cold, or by submitting it to forcible compression; as a matter of fact many gases have been liquefied by one of these means, or by both combined. Those gases which have hitherto resisted all attempts to liquefy them, and which therefore approach more nearly to the nature of perfect gases, are six in number, hydrogen, oxygen, nitrogen, nitric oxide, marsh gas, and carbonic oxide. Ordinary gases which are condensible to liquids, and the respective pressures under which this effect takes place, are stated in the following table:—

APPROXIMATE MAXIMUM PRESSURES OF CONDENSIBLE GASES AT 0° C.

Symbol.	Name of Gas.	Atmospheric Pressure.	Theoretic Condensation.
SO_2	Sulphurous oxide,......	1·5	$\frac{2}{3}$
C_2N_2	Cyanogen,............	2·5	$\frac{2}{5}$
H_3N	Ammonia,............	4·0	$\frac{1}{4}$
H_2S	Sulphuretted hydrogen,..	10·0	$\frac{1}{10}$
HCl	Muriatic Acid,..........	26·0	$\frac{1}{26}$
N_2O	Nitrous oxide,..........	33·0	$\frac{1}{33}$
CO_2	Carbonic acid,..........	38·0	$\frac{1}{38}$

The condensation of some gases to liquids has, during the last few years, become of such importance as to constitute a distinct trade, and the liquefied gases contained in suitable iron bottles may be purchased at a fair and reasonable rate; especially is this the case with nitrous oxide, owing to its extensive use in dental operations as an anæsthetic. The means used for the compression of the gas are purely mechanical, the gas being compressed by a steam force pump into a wrought-iron cylinder of suitable size, care being taken to prevent any undue rise of temperature. Liquids resulting from the liquefaction of gases usually expand and contract to a much greater extent under the influence of heat than liquids under ordinary pressures. No gas has as yet been found to solidify by pressure alone; but it sometimes happens, as in the cases of carbonic acid and nitrous oxide, that if a portion of the liquefied gas be allowed to evaporate, that the temperature of another portion will be so reduced as to cause it to pass readily into the solid state. In this way extremely low temperatures may be obtained; thus the temperature of the solid carbonic acid is —78° C., and if it be mixed with ether the temperature is further considerably reduced, owing to the increased rapidity of its evaporation; in this manner —100° C. may be reached. Liquid nitrous oxide boils at —88° C., and if mixed with bisulphide of carbon, in which it dissolves, will reduce the temperature to —140° C.

Measurement of Gases.—The volume of a gas, or a mixture of gases, is usually stated after correction to the standards of temperature and pressure, viz., 0° C. and 760^{mm} pressure of mercury. If gases be inclosed over mercury or water, certain other corrections are necessary for the excess or deficiency of the height of the mercury or water, relatively to the external pressure, also for the curve or meniscus which is invariably found at the surface of either. Tubes and vessels which are graduated for accurate experiments must be carefully calibrated before reliance can be placed upon the results obtained. As the corrections for temperature and pressure are the most important, and are the most frequently required, they will be the only ones described here. All gases expand and contract equally when exposed to the same change of temperature. A gas being measured at the freezing point will be found, if its temperature be raised to 1° C., to have increased $\frac{1}{273}$ of its volume, or $\frac{1}{490}$ if the Fahrenheit scale be adopted, and this amount of increase is found to be perfectly regular; thus, if the temperature be raised 2° C., the gas will have increased $\frac{2}{273}$ in volume. The fractional number representing this increase is the co-efficient 0·003665—one volume of gas at 0° C. becoming 1 vol. + 0·003665 at 1° C.; thus it becomes a simple matter to correct a gas measured at any temperature for any other temperature by the following formula:—

As $273 + t$ is to $273 + t'$, so is the volume at t degrees above or below zero C. to volume at t' degrees.

The correction for pressure is even more simple, for according to BOYLE and MARRIOTT'S law the volume of a gas varies inversely as the pressure, so that the formula—

$$P \text{ is to } P' \text{ as is } V \text{ to } V'$$

expresses the necessary calculation, or both corrections may be embodied in one calculation, according to the following formula, V′ being the volume required:—

$$V' = V \frac{P}{P'} \cdot \frac{273 + t'}{273 + t}$$

Specific Gravity of Gases.—The following is a table of the specific gravities of the most commonly occurring gases, at 4° C. and 760^{mm} pressure, referred to air, and also to hydrogen, as a standard.

TABLE OF SPECIFIC GRAVITIES.

Name of Gas.	Specific Gravity.	
	Air = 1·000.	H = 1.
Ammonia,	0·589	8·50
Carbonic acid,	1·529	22·80
Carbonic oxide,	0·967	14·00
Chlorine,	2·470	35·50
Coal gas (variable),	0·500	—
Cyanogen,	1·806	26·0
Hydrofluoric acid,	0·689	10 0
Hydrochloric acid,	1·247	18·25
Hydrogen	0·069	1·00
Nitric oxide,	1·039	15·00
Nitrous oxide,	1·527	22·00
Nitrogen,	0·971	14·00
Marsh gas,	0·557	8·00
Olefiant gas,	0·978	14·00
Oxygen,	1·105	16·00
Phosphoretted hydrogen,	1·185	17·00
Sulphuretted hydrogen,	1·191	17·00
Sulphurous acid,	2·247	32·00

As referred to hydrogen as a standard, the specific gravities of the elementary gases are found to be identical with the numbers representing their atomic weights, while those of the compound gases are their molecular weights divided by 2.

Transpiration of Gases.—This title is given to a number of observations which have been made, principally by GRAHAM, on the passage of gases through very fine tubes. The laws of diffusion, which have been already mentioned, only hold good so long as the minute apertures have no appreciable thickness. When this becomes the case a totally distinct series of laws comes into operation, which cannot be expressed by any simple statement. The following facts have been made out:—

1. The rate of transpiration increases directly as the pressure.

2. With tubes of equal diameter the volume transpired in equal times is inversely as the length of the tube.

3. As the temperature rises the rate of transpiration becomes slower.

4. The rates of transpiration of different gases bear a constant relation to each other, apparently in no way connected with their densities.

Tubes of copper, glass, and stucco were used with similar results. The length of the tube in any case should exceed its diameter by not less than 4000 times.

Preparation and Properties of Gases.—Before entering upon a technical description of the manufacture of "coal gas," which as a technical subject occupies the greater part of this article, a short description of the preparation and properties of each of the most commonly known gases will be given. The gases will follow in alphabetical order.

Ammonia Gas, known in ancient times as *volatile alkali;* formula, NH_3; composition, 1 volume of nitrogen and 3 volumes of hydrogen united together to form 2 volumes of ammonia. This gas is found both free and combined in nature. The atmosphere from all districts is found to contain traces, which are derived from the decomposition of nitrogenous organic matter. Plants appear to be unable to remove this ammonia from the air directly; but when it is carried down by the rain, and sinks into the soil, they readily assimilate it. Ammonia is allied in its nature to the alkalies potash and soda, but is a much weaker base than either—potash, soda, and even the alkaline earths being able to decompose all ammonia salts without exception, expelling the ammonia; in this manner the gas may readily be obtained from its salts. If one part of ammonium chloride (sal ammoniac) be mixed with two parts of caustic lime, and the mixture gently heated in a flask or other suitable vessel, the whole of the ammonia contained in the ammonium chloride will be expelled, and may be collected either by displacement or over mercury, but not over water, owing to its great solubility in that liquid. The action which takes place is represented as follows:—

$$2NH_4Cl + CaO = 2NH_3 + CaCl_2 + H_2O,$$

water and calcic chloride being formed.

Ammonia gas is a colourless gas, having a powerful pungent odour and taste; it supports neither combustion nor respiration, but is itself feebly combustible, burning with a yellowish flame; its specific gravity is 0·59, and it shows a marked alkaline reaction, forming by its union with acids a series of salts resembling those of potassium and sodium. The most remarkable property of ammonia is its great solubility in water; 1 volume of water at the ordinary temperature will absorb 700 volumes of ammonia gas, and will then measure 1½ volume of a solution of ammonia of a specific gravity 0·88; this is the strongest *liquor ammoniæ* of the shops. Various solutions containing less ammonia, and of a greater specific gravity, may be prepared, the specific gravity forming a perfectly accurate measure of the amount of ammonia contained. Dry ammonia gas may be liquefied by a cold of —40° C., or by a pressure of six atmospheres at a temperature of 15° C., forming a colourless mobile liquid of a specific gravity 0·76, which boils at —33·7° C. At a temperature of —75° C. this liquid may be frozen.

Atmospheric Air.—Atmospheric air was classed by the ancients as among the four primary elements. That a gaseous envelope surrounded our globe, and that it probably had weight, was known by ARISTOTLE. The physical properties of the air, however, remained but little known until the time of GUERICKE and TORRICELLI, when, by the discovery of the pressure and density of air, the foundation was laid for much fuller investigation.

The atmosphere envelopes the earth at all points, and extends into space to a somewhat uncertain height. The atmosphere probably has a limiting surface, and does not in an attenuated state pervade the whole of space. This is gathered from observations made upon the fixed stars, and from the fact that some of the planets and the moon do not possess an atmosphere. The probable height of the atmosphere above any point on the earth's surface is from 40 to 45 miles.

The average weight of the atmosphere at the sea level is equal to a pressure of not quite 15 lbs. per square inch—or the weight of the atmosphere upon a square inch will balance a column of mercury equal to a weight of nearly 15 lbs. This pressure decreases as the distance from the surface of the earth's surface increases. In this manner the barometer is used as an instrument for the measurement of heights.

The composition of the atmosphere remained unknown until long after its physical properties had been established, it being thought at one time to be homogeneous and elementary. Lavoisier, following up the experiments upon oxygen gas made by Priestley, announced, in 1774, that it was composed of two gases occurring in unequal proportions. These gases he named oxygen and azote, or nitrogen, the oxygen being identical with Priestley's vital air. Lavoisier stated the proportions of these gases to be oxygen one-fifth, and nitrogen four-fifths, in every five volumes of air, and this proportion has been found to express accurately the fact. It was disputed for some time as to whether atmospheric air was to be regarded as a chemical combination of these two gases, or whether it was in reality a mechanical mixture, and investigations to ascertain the precise amount of oxygen and nitrogen present were undertaken by Dalton, Gay Lussac, Dumas, and Boussingault.

From the results of these experiments it is shown that, although there is a surprising uniformity in the results obtained from samples of air taken from various parts of the globe, yet that the proportions of the two gases are not absolutely constant. This fact, and also that the gases may be in many ways mechanically separated from each other, is sufficient to establish the fact of the air being a mechanical mixture. In addition to these two principal constituents, there are certain others present in very small quantities: these are aqueous vapour, carbonic acid gas, ammonia, and organic matter; and although the quantity of these substances varies to a much larger extent, and is more influenced by local position than the oxygen and nitrogen, yet they may be looked upon as definite constituents in the composition of air.

TABLE OF COMPOSITION OF AIR.

	Volume.	Weight.
Nitrogen,	79·19	76·99
Oxygen,	20·81	23·01
	100·00	100 00
Aqueous vapour (average),	1·40	0·87
Carbonic acid,	0 14	0·06

Ammonia, about 1 part per million.
Organic matter, variable.
1 cubic foot of air = 527 grains.

Carbonic Oxide.—A gaseous compound of carbon and oxygen, in which the carbon is incompletely oxidized; formula, CO; composition, 1 volume of carbon vapour (hypothetical) and 1 volume of oxygen united to form 2 volumes of carbonic oxide. Carbonic oxide may be obtained in a variety of ways, the principal of which are, the oxidation of carbon in the presence of an insufficient supply of oxygen at a high temperature; the reduction of carbonic acid by carbon, metals, and other substances; by the passage of steam over red-hot carbon, and by the decomposition of organic bodies by heat. One of two methods is generally adopted for its preparation. In the first, oxalic acid is heated with five or six times its weight of strong sulphuric acid. Oxalic acid has the composition $H_2C_2O_4$; the sulphuric acid abstracts the elements of a molecule of water, while equal volumes of carbonic acid and carbonic oxide are liberated in the gaseous state, thus:—

$$C_2H_2O_4 - H_2O = CO_2 + CO.$$

If the mixture of these gases be passed through a solution of potash or soda, the carbonic acid will be retained, and the carbonic oxide may then be collected. The second method is that of heating crystallized ferrocyanide of potassium with ten or eleven times its weight of strong sulphuric acid, when the following decomposition takes place:—

$$K_4FeC_6N_63H_2O + 6H_2SO_4 + 3H_2O = 6CO + 3(NH_4)_2SO_4 + 2K_2SO_4 + FeSO_4.$$

By this latter process carbonic oxide may be obtained comparatively pure, very little carbonic acid being found in the first portion of gas. Towards the end of the distillation sulphurous acid is formed in some quantity.

The specific gravity of carbonic oxide compared with hydrogen is as 14 to 1, and to atmospheric air as 0·9706 to 1·0000: a hundred cubic inches weigh 29·0979 grains. It is fatal to animal life, causing giddiness and fainting when respired, even when diluted with a very large excess of air. When breathed pure, it produces almost immediately profound coma. It extinguishes flame, but burns with a peculiar and characteristic blue flame, producing carbonic acid. It may be exploded when mixed with oxygen. The temperature of an iron wire heated to dull redness is sufficient to inflame it. It has no colour, taste, or smell, and does not affect vegetable colours, nor occasion any precipitate with lime water. It is dissolved very sparingly by water which has been deprived of air; when burned in dry air or oxygen, carbonic acid is the only product of its combustion. Carbonic oxide reduces the oxides of many of the metals, especially copper, lead, tin, and iron; and in the smelting of iron this action is of very great importance.

Carbonic Acid Gas.—The second oxide of carbon, in which the carbon is completely oxidized. Formula, CO_2; 1 volume of carbon vapour and 2 volumes of oxygen forming 2 volumes of carbonic acid gas. This gas is produced whenever carbon or fuel containing carbon is burnt in a sufficient supply of air or oxygen; it forms the gaseous product of fermentation, and is obtained when carbonaceous matter undergoes decay; it is further produced when marsh or mine gas is burnt, and under these circumstances is called "choke damp." It occurs free in the atmosphere in the proportion of about 4 volumes in 10,000 of air, and in this form supplies the greater part of the carbon necessary for vegetable life; also it is found naturally in spring and well waters, and issues in some places from fissures in the earth. In union with calcium or chalk, or with magnesia, it forms large strata in the earth's crust. It may be best prepared by acting upon carbonate of lime, or chalk, with an acid, in which case the carbonic acid is expelled in its gaseous state.

$$CaCO_3 + 2HCl = CO_2 + H_2O + CaCl_2.$$

Calcium carbonate and hydrochloric acid give carbonic acid gas, water, and calcic chloride.

Properties—clear transparent gas, with sharp acid smell and taste, irrespirable, does not support combustion, is not itself combustible, of great weight, its density is 22 times that of hydrogen, 1·529 times heavier than air, and 1 cubic foot weighs 805·7 grains.

Owing to the extreme weight of this gas, and its dangerous character when breathed, great care should be taken before entering old cellars, wells, or brewer's vats, to see that the space is free from carbonic acid.

Carbonic acid is not a permanent gas: exposed to a pressure of 36 atmospheres, at 0° C., it passes into the liquid state, in which condition it may be retained in iron bottles or in sealed glass tubes; this liquid carbonic acid may be frozen to a white solid by exposing it to a cold of nearly —100° C., or if some of the liquid be allowed to evaporate into gas the cold so produced is sufficiently low to freeze a second portion of the liquid. Solid carbonic acid is a light snow white substance, lighter than water, that may be handled without danger, although its temperature is below —80° C., owing to the protection which a small cushion of vapour, with which it is at all times surrounded, affords: mixed with ether, which dissolves it, a very low degree of cold can be obtained.

Carbonic acid is soluble in water; the amount so dissolved varies considerably with the temperature. At ordinary temperatures water dissolves an equal volume of carbonic acid, at 0° nearly twice as much. As the weight of a gas dissolved by a liquid is proportional to the pressure, water may be made to dissolve a larger quantity of carbonic acid by forcing the gas into the water, and retaining it under pressure; this is largely taken advantage of in the preparation of effervescing drinks.

Chlorine, one of the few gaseous elements. Symbol, Cl.; atomic weight = 35·5.—A yellowish green gas, discovered by SCHEELE in 1774; it is never found free in nature, but largely in combination with sodium and potassium, these combinations, especially that of sodium, being of great commercial importance; certain other metals are also found in smaller quantities combined with chlorine. Chlorine is always obtained in the first instance from common salt, sodium chloride. If sodium chloride, black oxide of manganese, and sulphuric acid be warmed together in a flask the following reaction takes place:

$$2NaCl + MnO_2 + 2H_2SO_4 = Na_2SO_4 + Mn\ O_4 + 2H_2O + Cl_2.$$

Chlorine may also be easily prepared by heating hydrochloric acid with black oxide of manganese—the hydrochloric acid having been obtained from common salt by acting upon it with sulphuric acid—

$$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2.$$

Chlorine gas has a peculiar irritating smell; if taken into the lungs even in small quantities it produces violent inflammation, and if breathed causes death. The gas cannot be collected over water or mercury, owing to its solubility in the former, and its attacking the latter; but from its extreme weight it may be collected by displacement. Chlorine is 35·5 times heavier than an equal volume of hydrogen; its specific gravity referred to air is 2·5. Water dissolves chlorine to the extent at ordinary temperatures of 2·37 volumes; and if this solution be cooled to 0° C. a definite chlorine hydrate separates out in crystals, having the composition $Cl(H_2O)_{10}$. By inclosing these crystals in a sealed glass tube, and allowing the tube to attain the normal temperature, two layers of liquid will be obtained, one of which is liquid chlorine, the other water. The pressure required for the liquefaction of chlorine is about 5 atmospheres. Chlorine is not combustible, but supports ordinary combustion to a feeble extent, the chlorine uniting with the hydrogen to form hydric chloride, the carbon at the same time being separated; many metals, however, take fire spontaneously on being introduced into chlorine, uniting with it to form corresponding chlorides.

Chlorine is a powerful disinfectant, and if employed judiciously in this direction is very useful; also the bleaching properties of chlorine are of great importance. Chlorine bleaches all organic colouring matter, only, however, in the presence of moisture; the chlorine unites with the hydrogen of the water to form hydric chloride, the oxygen so liberated being the active bleaching agent, the process being in reality one of oxidation. Chlorine is unable to bleach mineral colours.

Hydrogen, Symbol H.—An elementary gas, without colour, taste, or smell, found free in nature only in volcanic actions, and in samples of meteoric iron; it occurs in combination with oxygen in water, and in organic substances, one-ninth of the weight of water consisting of this gas. It is most conveniently prepared from water, usually by the action of a metal, the metal uniting with the oxygen to form an oxide, the hydrogen being liberated. The metals of the alkalies decompose water at ordinary temperatures, liberating one-half of the hydrogen.

$$K + H_2O = \overset{\text{Potassic Hydrate.}}{KHO} + H.$$

Manganese and magnesium decompose water at the boiling temperature.

Zinc and iron will decompose water at a red heat, bismuth, copper, and lead at a white heat; while mercury, silver, gold, and platinum do not decompose water at very high temperatures.

Certain metals which under ordinary circumstances decompose water only at a high temperature, will do so much more easily in presence of an acid. The two principal methods by which hydrogen is obtained are by acting upon zinc with sulphuric acid and water, or by passing steam over red hot iron. In the first case the following action takes place—

$$H_2SO_4 + Zn = ZnSO_4 + H_2.$$

In the second,

$$4H_2O + Fe_3 = \overset{\text{Black oxide of iron.}}{Fe_3O_4} + H_8.$$

The gas may be collected over water, as it is soluble in it to an inappreciable extent.

Hydrogen is a permanent gas, the lightest of all known substances; specific gravity referred to air = 0·0692; 1 cubic foot weighs 36 grains; it is combustible, burning with a colourless almost invisible flame of great heat, producing water; it does not, however, support combustion or life. Hydrogen, if mixed with air or oxygen, forms explosive mixtures, which on ignition may become dangerous. Great care should be taken in the preparation and storage of this gas, to prevent the admixture of air.

Marsh Gas or Carburetted Hydrogen.—A compound of carbon and hydrogen, formula, CH_4; 1 volume of hypothetical carbon vapour and 4 volumes of hydrogen unite to form 2 volumes of marsh gas, so called on account of its occurrence as a product of the decomposition of vegetable matter in marshy or swampy districts. This gas from the same source forms the fire damp or mine gas of the coal measures. It is also evolved in volcanic districts. It is best prepared by heating in an iron or copper vessel to a red heat a mixture of acetate of soda and caustic soda.

$$NaC_2H_3O_2 + NaHO = Na_2CO_3 + CH_4.$$

Marsh gas is a colourless inodorous gas which has never been converted into a liquid. It is combustible, burning with a feebly luminous flame without smoke, forming carbonic acid and water. It requires for its complete combustion twice its volume of oxygen, or 10 times its volume of air, under which circumstances it forms an explosive mixture which in confined places is exceedingly dangerous. As a slight safeguard, however, marsh gas requires a high temperature to inflame it; an ordinary red heat is not sufficient. Marsh gas is eight times heavier than hydrogen; its specific gravity as referred to air is 0·559; 1 cubic foot weighs 292 grains; it occurs as a large constituent in all ordinary illuminating gases.

Muriatic or Hydrochloric Acid Gas.—A compound gas, formed by the direct union of chlorine with hydrogen; formula, HCl; composition, 1 volume of chlorine and 1 volume of hydrogen united to form 2 volumes of hydrochloric acid gas. This gas forms the only known compound of hydrogen with chlorine, and it may be obtained by simply exposing the mixed gases to the influence of sunlight. In direct sunlight the union takes place with explosive violence, but in diffused light more gradually. The same effect of sudden combination is likewise produced if a flame be brought in contact with the mixed gases.

Hydrochloric acid gas is best prepared by acting upon common salt with sulphuric acid, thus:—

$$2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl,$$

$$\text{or}\left\{\begin{array}{l} NaCl + H_2SO_4 = NaHSO_4 + HCl \\ NaHSO_4 + NaCl = Na_2SO_4 + HCl. \end{array}\right.$$

The gas so obtained is a transparent colourless gas, which fumes strongly in air, owing to its condensation of the moisture which is present. It possesses a strong acid reaction, but has no bleaching power. The gas cannot be collected over water on account of its great solubility, but it may be collected over mercury or by displacement with slight loss. Hydrochloric acid gas is 18·25 times heavier than hydrogen; its specific gravity referred to air is 1·269: 1 volume of water at 0° C. absorbs 480 times its volume of this gas, giving a solution which has a specific gravity of 1·21, and which contains 43 per cent. of the gas. This liquid fumes in air like the gas itself, and forms the strongest hydrochloric acid of commerce. Very large quantities of this gas are produced as a by product in the alkali manufacture. Hydrochloric acid gas is incombustible, and does not support combustion; it produces fatal effects if breathed in any quantity; it may be condensed to a liquid by a pressure of 40 atmospheres.

Nitric Oxide.—A gaseous oxide of nitrogen, having the formula NO, composed of 1 volume of nitrogen and 1 volume of oxygen united to form 2 volumes of nitric oxide. This body is never found free in nature; in presence of free oxygen it forms a red gas (hyponitric acid), and by this reaction it may be distinguished from all other gases. Nitric oxide is best prepared by acting upon nitric acid with a metal when the acid is deoxidized. Copper or mercury are best suited for this purpose. The reaction is as follows:—

$$3Cu + 8HNO_3 = 3Cu(NO_3)_2 + 2NO + 4H_2O.$$

The nitric oxide obtained in this way is not quite pure, but if the vessel in which the preparation is carried be kept cool the mixture of other oxides of nitrogen is not great. Nitric oxide may be collected over water. The gas is transparent and colourless; is not combustible, and does not easily support combustion unless the combustible body be burning vigorously. Nitric oxide is 15 times heavier than hydrogen, its specific gravity to air being 1·038. It has never been reduced to the liquid state.

Nitrous Oxide (also known as laughing gas).—An oxide of nitrogen, containing proportionately less oxygen than nitric oxide. Formula, N_2O. It may be obtained by deoxidizing nitric oxide, or by submitting nitrate of ammonia to heat. The latter is the usual process for its preparation. Crystallized nitrate of ammonia, introduced into a flask fitted with a delivery tube and heated to about 130° C., is completely decomposed into nitrous oxide gas and water, thus—

$$NH_4NO_3 = N_2O + 2H_2O.$$

The gas, which comes off rapidly, may be collected over water with a slight loss, one volume of water at 0° C. dissolving 1·3 volume of gas.

Nitrous oxide is not combustible, but is an excellent supporter of combustion, second only in this respect to oxygen; from which it may be distinguished, however, by not giving rise to red fumes when mixed with nitric oxide. It is a heavy gas, being 22 times heavier than an equal volume of hydrogen; its specific gravity referred to air is 1·53. This gas has remarkable physiological properties, producing, when breathed, a species of intoxication, whence its name, laughing gas. It is capable also of being used as an anæsthetic in short surgical operations. Nitrous oxide, under a pressure of thirty atmospheres at 0° C., is converted into a liquid. If this liquid be cooled while under pressure to —115° C., it is frozen into a clear transparent solid; also, as in the case of carbonic acid gas, if the liquid is allowed to escape into the air, a portion of it is solidified, owing to the lowering of the temperature. Liquid nitrous oxide is made to a somewhat large extent, and supplied in iron vessels for the use of dentists and others who have occasion to use the gas for the purpose of producing insensibility to pain. Mixed with bisulphide of carbon, the lowest temperature yet obtained has been reached, viz., —140° C.

Nitrogen or *Azote*, the elementary gas which forms the largest constituent of atmospheric air, in which it occurs in the free state. Nitrogen is also found occurring naturally in combination, in the form of nitrate of potash or soda. Natural beds of these substances occur at various places, especially in Chili and Peru. It is also found in the form of ammonia as a product of the decomposition of nitrogenous organic bodies. Most animal and vegetable substances contain nitrogen as a constituent.

The processes generally adopted for its preparation are those by which the oxygen is removed from atmospheric air. If an excess of phosphorus be burned in a confined vessel containing air, the oxygen will entirely unite with the phosphorus, forming phosphoric acid. The residual nitrogen may then be transferred over water; or the experiment may be performed in a vessel standing over water, in which case the phosphoric acid will be dissolved, and the nitrogen may be obtained in a pure state. The reaction which takes place may be expressed thus—

$$P_2 + O_5 = \overset{\text{Phosphoric acid.}}{P_2O_5}.$$

If larger quantities of nitrogen are required, it is preferable to obtain it by passing pure air over red hot copper placed in a furnace, when the same result is obtained, copper oxide being formed.

All combustibles which burn in air do so by abstracting and uniting with the oxygen which it contains; but in the majority of cases the removal of the oxygen is not complete, the combustion ceasing before this point is reached. In the case of phosphorus, however, perfectly pure nitrogen may be obtained.

Nitrogen is a transparent colourless gas, having few positive qualities. It does not act in any way upon vegetable colouring matters, and does not render lime water turbid. It neither supports combustion nor is itself combustible. It cannot support life, but if breathed has no positive injurious action. In air it acts as a diluent of the oxygen, for which purpose its properties are admirably adapted. The gas is slightly lighter than air, its specific gravity being 0·972; it is 14 times heavier than an equal volume of hydrogen gas; one cubic foot of nitrogen weighs 512 grains.

In its free state nitrogen is one of the most inert of all the elements; in combination, it becomes one of the most powerful.

Olefiant Gas (heavy carburetted hydrogen, or ethylene).—This gaseous compound of carbon and hydrogen, having the formula C_2H_4, occurs as one of the constituents of coal gas, and is also generally obtained when substances rich in carbon are submitted to the process of destructive distillation. It is most conveniently prepared by heating one measure of alcohol with two measures of strong sulphuric acid; the alcohol loses the elements of a molecule of water, which unites with the sulphuric acid.

$$\overset{\text{Alcohol.}}{C_2H_6O} + H_2SO_4 = H_2SO_4 + H_2O + \overset{\text{Olefiant gas.}}{C_2H_4}.$$

Towards the end of the operation, or if the heat be too strong, a more complicated reaction takes place, sulphurous acid, carbonic acid, and ether being obtained. In preparing olefiant gas, some sand should be placed in the flask containing the mixture to prevent undue frothing, which otherwise is likely to occur. The gas obtained may be collected over water; it is colourless, but has a sweetish smell and taste; it burns with a very luminous smoky flame, forming carbonic acid and water. It is not a permanent gas, having been liquefied at a high pressure. Its name (oil-forming gas) is due to the fact, that with chlorine or bromine it unites to form oily liquids, $C_2H_4Cl_2$ and $C_2H_4Br_2$. Olefiant gas is decomposed by passage through a red hot tube, carbon being deposited, and small quantities of more highly condensed hydrocarbons formed. The specific gravity of this gas is 0·972 referred to air, and 14 referred to hydrogen.

Oxygen is the most abundant of all elementary substances, forming as it does one-fifth by volume of the atmosphere, eight-ninths by weight of water, and about one-half of the weight of the known crust of the earth, which may be taken roughly to consist of silica and alumina. All the elements, with the exception of fluorine, combine with oxygen to form oxides. Animal life is entirely dependent upon it for continuance, and on this account it received its original name of "vital air." All ordinary combustion is obtained by the union of the combustible with oxygen to form products which are oxides.

The preparation of this gas may be carried out in a variety of ways, and it may be obtained from a large number of substances. Certain metallic oxides, when heated, part with either a part or the whole of their oxygen. By heating mercuric oxide Priestley first obtained the gas—$HgO = Hg + O$.

Black oxide of manganese is a cheaper material for the purpose. This substance occurs naturally as the mineral pyrolusite. If this be heated to redness in an iron or copper vessel it parts with one-third of its oxygen, which may be collected—

$$3MnO_2 = Mn_3O_4 + O_2.$$

A better way than either of the above is, however, by heating potassic chlorate ($KClO_3$), which loses the whole of its oxygen at a temperature of about 300° C.

$$KClO_3 \quad = \quad \overset{\text{Potassic Chloride.}}{KCl} \quad + \quad O_3.$$

The temperature required for the decomposition of the pure salt is high, but if a little black oxide of manganese, or oxide of copper, be mixed with the chlorate, the decomposition will proceed more regularly and at a much lower temperature. The metallic oxide acts simply by its presence, and does not undergo any decomposition. This experiment may be made in a glass flask, with cork and conducting tube, the oxygen being collected over water.

Another method for the preparation of oxygen has been introduced lately. This depends upon the fact that oxides of manganese, heated with alkalies and air, are capable of absorbing the oxygen from the air, and of subsequently giving it up again if heated in a current of steam. Where large quantities of oxygen are wanted of no great purity, this process would probably prove the cheaper.

Oxygen gas is a transparent colourless gas, without taste or smell. It has never been reduced to the liquid state. Most of the elements unite directly with oxygen, and all, with the exception of fluorine, either directly or indirectly. All actions and combinations which take place with the oxygen of the air do so much more energetically in pure oxygen; and many metals which will not burn in air will do so readily in oxygen.

The process of combination with oxygen, as in all other chemical actions, is attended with heat; and when this heat is sufficient to render the particles of matter luminous, combustion is said to take place.

The density or specific gravity of oxygen is—referred to air, 1·1056; to hydrogen it is 16. A cubic foot of oxygen weighs 542 grains.

Sulphurous Acid Gas.—An oxide of sulphur, having the formula SO_2; 2 volumes of oxygen and 1 volume of sulphur vapour uniting to form 2 volumes of sulphurous acid. This gas is found in nature issuing from volcanic craters and certain fissures in the earth. It is formed when combustibles containing sulphur, such as common coal, are burnt, but is so readily oxidized into sulphuric acid that it is not frequently met with. Whenever sulphur is burnt in air or oxygen, sulphurous acid is the product, and the gas may be prepared in this way; but it is found preferable to obtain it by acting upon sulphuric acid with a metal. If copper or mercury be heated in a flask with strong sulphuric acid the following change takes place:—

$$Cu + 2H_2SO_4 = CuSO_4 + 2H_2O + SO_2.$$

The gas so produced cannot be collected over water, as it dissolves in it to a considerable extent; 1 volume of water dissolving 43 volumes of the gas at ordinary temperatures, giving a liquid having strongly acid properties, but which speedily becomes oxidized into sulphuric acid. Sulphurous acid is a colourless gas with a characteristic pungent odour, and exhibits strong acid properties; it extinguishes combustion, and if breathed is fatal to life. It is a powerful bleaching agent, and is used for this purpose in cases where chlorine is unsuitable; it is likewise an antiseptic, and is used commercially as a means to arrest fermentation. Sulphurous acid gas is extremely heavy, its specific gravity being 2·247 (air = 1) 16 (H = 1); the gas may easily be condensed to a liquid either by exposing it to a pressure of from 2 to 3 atmospheres, or to a cold of —10° C., a degree of cold which may be obtained by a mixture of ice and salt.

Sulphuretted Hydrogen, H_2S.—This gas is found issuing from volcanoes, also in certain mineral springs, and is frequently produced when substances containing sulphur undergo decomposition. The gas has a most offensive odour, which is, however, quite characteristic; the odour appears to be worse when the gas is very largely diluted. It can be best prepared by acting upon a metallic sulphide with an acid; thus iron sulphide, formed by fusing iron and sulphur together, if treated with dilute sulphuric acid, forms iron sulphate and sulphuretted hydrogen—

$$FeS + H_2SO_4 = FeSO_4 + H_2S.$$

The gas should be collected over hot water, as it is soluble to some extent in cold water: 1 volume of water at ordinary temperatures dissolves 3·2 volumes of gas. The gas is combustible, burning with a bluish flame, forming in excess of air sulphurous acid and water. The gas, if heated, causes headache and nausea, and sometimes fainting. Sulphuretted hydrogen exhibits acid properties, hence it is also called hydrosulphuric acid; its specific gravity referred to air is 1·192, to hydrogen it is 17; at a pressure of 17 atmospheres it can be reduced to a liquid and at —85° C. it forms a white crystalline solid. The solution of this gas in water is of great use in the laboratory as a means of separating the metals into groups.

COAL GAS.—The history of the development and progress of gas lighting affords us an unparalleled example of the rapid progress which frequently attends a new branch of industrial manufacture, and yet perhaps no commercial industry passed through greater vicissitudes before becoming an established success. Many facts were known about coal gas which pointed to the possibility of its employment as a means of artificial illumination, but it was not until many years subsequently that even an attempt was made to make any practical use of what was known on the subject. It is somewhat curious that the practical introduction of gas lighting as a commercial success was mainly due to a man who was, comparatively speaking, an outsider, and not to any of those whose experimental labours might have suggested the possibility of great results. The parallel is frequently observed in cases where the development of a new industry has been the outgrowth of scientific experiments; and it is but too often the case that those who originally obtained the results have not carried their generalizations further than the laboratory, and the germs of some great invention have thus slumbered in the dusty records of a scientific journal. Afterwards arises some far-seeing man with views in advance of his time, who recognizes the importance of the results, and by his indomitable energy and perseverance overcomes all the difficulties which beset his path, and fighting the battle against public prejudice, never rests until he has established a new enterprise on the sure footing of a commercial success. Such a man was F. A. WINSOR, and he has with justice been termed "the Father of modern gas lighting."

Turning to the very earliest account of what was known on the subject of coal gas, we find that the discovery and earliest observation of elastic aeriform fluids capable of being inflamed, and of affording light and heat, must have undoubtedly been of great antiquity. The most ancient writings contain notices of inflammable vapours springing from fissures and cavities in the earth. It is evident, therefore, that gas of this description being a natural production, no such individual as the inventor or discoverer of illuminating gas ever exist d. Modern chemistry has no difficulty in explaining the natural formation of inflammable gas, which is generally found to occur in those districts which have underlying strata of coal or some rock of a bituminous nature. Here, at a great depth, and under conditions of heat and pressure, changes are continually occurring in which gaseous compounds, such as light carburetted hydrogen or marsh gas, are being evolved, and these gases either find their way to the surface through some pre-existing channel, or accumulate in some underground cavity, to be set free by the miner's axe in the form of the well-known "fire damp." As already stated, jets of flaming gases issuing from the ground have attracted notice from a very early date; and savage tribes, owing to the grandeur of the spectacle, produced apparently without any supply of fuel, considered the spots where such emanations occurred as the abode of their gods. The well-known fires of Baku still burn, and are due to the ignition of marsh gas charged with naphtha vapour. They are objects of worship by the savages in the neighbourhood of the Caspian Sea. In China the borers for salt water often meet with streams of combustible gases, which they employ for illuminating factories and evaporating brines. The Chinese were, consequently, acquainted with the use of gas long before the knowledge of its application was acquired by Europeans. Some of the earlier nations considered fire as typical of divinity, and one can scarcely wonder at the feelings of awe and veneration occasioned by mysterious outbursts of flame, the origin of which appeared utterly incomprehensible. Here superstition erected its altars over such flames, and claimed the interference of the gods to sustain the perpetual miracle. Numerous conjectures have been made to account for the almost perpetual fires which were kept burning on many ancient altars. They are made the subject of special mention by STRABO and PLUTARCH, who state that, when they happened from any cause to become extinguished, they were relighted by invisible means.

All, however, that had been observed in ancient times with reference to inflammable vapours, was far from leading to any attempt to collect or use them. Their very nature and composition were unknown, and the most mistaken ideas prevailed as to their real character and origin. It was not until the science of chemistry had shown the erroneous nature of many of the prevalent ideas as to the constitution of matter, and had proved that the then so called elements were capable of resolution into far simpler forms, that the first glimpses of the real character of these inflammable gases became apparent. The analogy was then perceived, which existed between the combustible vapours given off from coal, wood, and oils, under the influence of heat, and the gas which found its way to the surface of the earth as a natural product. Although the application of the gas produced by the distillation of pit coal as a means of obtaining artificial light appertains to modern times, yet the germ of it may be traced back nearly two centuries. We read that as far back as the year 1659, THOMAS SHIRLEY, commenting on the exhalations from the burning well at Wigan, in Lancashire, attributes the phenomena to the subjacent coal beds; while in 1664 the observation was made by Dr. CLAYTON, that combustible illuminating gases were formed during the decomposition of coal by heat, and that they could be collected. One hundred years afterwards practical application was made of the fact, but by mere accident. In 1787 Lord DUNDONALD, of Culross Abbey in Scotland, took out a patent for making coal tar, and erected near the Abbey a series of ovens for this purpose. The tar was conducted by pipes from the condensers into cylinders of brickwork, each of which had a small opening at the top for the escape of the incondensible part of the products. To these openings the workmen were in the habit of attaching a cast-iron pipe by means of a mass of soft clay, and lighting the gas at the other end to give them light during the darkness. His lordship, also, was in the habit of burning the gas in the Abbey as a curiosity; and for this purpose he had a vessel constructed resembling a large tea-urn, which he frequently caused to be filled with gas, and carried up to the Abbey to light the hall, especially when he was entertaining company.

The first record of a really authentic nature with regard to an experiment on the destructive distillation of coal and production of illuminating gas, is to be found in a work by Dr. STEPHEN HALES, on "Vegetable Statics," published in the year 1726. The statement is here made, that from the distillation of 158 grains of Newcastle coal, 180 cubic inches of air, (gas) were obtained weighing 51 grains; and it is somewhat curious, that when this result is calculated to cubic feet of gas per ton of coal, the quantity thus obtained does not materially differ from the yield of the same coal at the present day. In the year 1739 the results of Dr. CLAYTON appeared in the transactions of the Royal Society, and the experiments there recorded are chiefly interesting from the fact that the gas produced from the coal was stored in bladders, and consequently we have here the first record of the practicability of storing coal gas. Dr. WATSON subsequently proved, in 1767, that this same coal gas retained its inflammability after passing through water.

Still further on, in the year 1792, WILLIAM MURDOCH, a Scotchman, made a series of experiments at Redruth, in Cornwall, on the quantities and qualities of the gases produced by the destructive distillation of various animal and vegetable substances. MURDOCH not only experimented on different varieties of coal, and varied the size and shape of the orifices from which the gas was burned, but he likewise endeavoured to effect a certain degree of purification of the crude gas. For this purpose, however, he does not appear to have used anything but water; the use of lime being introduced by Dr. HENRY and Mr. CLEGG. MURDOCH continued his experiments until the year 1798, when he was removed from Cornwall and appointed to a position of importance in the works of Messrs. BOULTON and WATT in Soho, and there he constructed an apparatus for the manufacture of coal gas, and lighted part of the Soho Foundry. He afterwards extended the same apparatus, so as to give light to all the principal shops in the neighbourhood, where it was in regular use to the exclusion of other artificial light; and finally, in 1805, he fitted up the gas apparatus in Messrs. PHILLIPS and LEE'S cotton mill; from which time its use gradually extended to all the cotton mills in the kingdom.

In the year 1799 LEBON lit his house in Paris with coal gas, causing as much astonishment as MURDOCH was occasioning in England. F. A. WINSOR happening to be at Brunswick at about the same time, read an account of LEBON'S experiments, and was forcibly struck with the possible importance of the results. Coming soon after to England, he endeavoured by every means in his power to advance the project of general illumination by coal gas. In 1803 he lit the Lyceum with gas as an experiment. Afterwards, in 1806, he took out a patent in connection with the subject, and by continued lectures and experiments endeavoured to overcome the public prejudice against the universal adoption of the new light. As a further means for insuring this, WINSOR endeavoured to get up a joint stock company; but in this he did not succeed until 1810, when an Act of Incorporation was obtained for the company, under the title of "The Gas Light and Coke Company," the royal charter, however, not being granted until 1812.

The new company at first made little or no progress towards becoming a commercial success, and it was not until they were fortunate enough to secure the services of Mr. CLEGG that the aspects of the company began to appear somewhat more favourable.

Gas was introduced in London at Golden Lane, 16th August, 1807. Pall Mall was lit by it in 1809. In 1813 Westminster Bridge was first lighted by gas, and in the following year the parish of Westminster itself had gas lights substituted for the oil lamps. In the same year (1814) a general illumination took place on the visit of the allied sovereigns to England, and in 1815 the Guildhall was first lighted. The success of the new light had by this time become thoroughly established, and it was not long before several rival companies started into existence—the City of London, the Phœnix or South London, and the Imperial; while companies were at the same time started in many of the leading towns in England and Scotland, all of which were in operation by 1819. Paris was lighted in 1820, and from that time to the present lighting by gas has steadily progressed and increased, until at the present time there are works, such as the Beckton station of the Chartered Company and the Bromley works of the Imperial, each producing their millions of cubic feet per diem.

The following statistics from a recent paper by CHUBB may be interesting on the subject of the magnitude of the present metropolitan gas supply. The share and loan capital of the companies amount to rather more than £11,000,000 sterling, and the maximum rate of dividend allowed to be paid on the total share capital averages 8·7 per cent. There are, in the aggregate, upwards of 1,500,000 tons of coal used every year in the manufacture of gas in the metropolis, and the quantity of gas annually consumed amounts to about 13,000,000,000 of cubic feet. There are at present 54,119 lamps in the public streets of London lighted by means of gas; and the mains of all the companies, of various sizes, from 4 feet to 3 inches in diameter, reach the enormous length of 2000 miles. Such is the wonderful extent to which modern gas manufacture has developed.

Nature of Illuminating Gas.—The gas ordinarily used for illuminating purposes is a mechanical mixture of various gases, some of which are luminous, while others have no value as illuminating agents. Besides the substances present which may be considered as true gases, there are also the vapours of different substances which in their normal condition exist as solids or liquids; and there is but little doubt that a considerable part of the illuminating value of gas is due to the vapours of these substances.

The following table by Dr. LETHEBY will show the principal substances present in ordinary purified coal gas:—

CHIEF CONSTITUENTS OF COAL GAS.

	Volume Per Cent.
Hydrogen,	25 to 50
Light carburetted hydrogen, CH_4,	35 " 52
Condensible Hydrocarbons, Olefiant gas, C_2H_4, Propylene, C_3H_6, Butylene, C_4H_8,	3 " 20
Benzol and its series,	?
Acetylene, C_2H_2,	?
Naphthalin, $C_{10}H_8$,	?
Carbonic oxide, CO,	5 " 9
Carbonic acid, CO_2,	0 " 2
Cyanogen, CN,	?
Ammonia, NH_3,	0·00 " 0·06
Bisulphide of carbon, CS_2,	0·004 " 0·04
Aqueous vapour, H_2O,	0·60 " 2·50
Oxygen,	0·00 " 0·10
Nitrogen,	0·00 " 8·00

To which may be added sulphocyanogen, which is likewise always present in small quantity.

The average composition of London gas is given by the same author as follows :—

AVERAGE COMPOSITION OF LONDON GAS.

	Common Gas. 12 Candles.	Cannel Gas. 20 Candles.
Hydrogen,	46·0	27·7
Light carburetted hydrogen,	39·5	50·0
Condensible hydrocarbons,	3·8	13·0
Carbonic oxide,	7·5	6·8
Carbonic acid,	0·6	0·1
Aqueous vapour,	2 0	2·0
Oxygen,	0·1	0·0
Nitrogen,	0·5	0·4
	100·0	100·0

The analyses of which the above figures are the average, although made some time ago, represent fairly the composition of ordinary coal gas, with the single exception that the gas, as now supplied for the major part of the London district, would contain less carbonic acid than is shown in the tables.

The value of gas as an illuminating agent may be said to depend on the amount of hydrocarbons present, and on the relation which the carbon bears to the hydrogen in these substances. In marsh gas, CH_4, which is, practically speaking, non-luminous, the percentage composition is, carbon, 75·4, and hydrogen, 24·6. In olefiant gas, C_2H_4, the carbon is 86, and the hydrogen 12; and the gas possesses a correspondingly greater amount of illuminating value. In acetylene, C_2H_2, we have a gas of still greater illuminating value, the proportion of carbon to hydrogen being also greater, the percentage composition being carbon, 92·3, and hydrogen, 7·7. In benzol, C_6H_6, we have the same percentages, while in napthalene, $C_{10}H_8$, a still higher ratio between the carbon and hydrogen exists, and a correspondingly increased value in light-giving power. It was formerly taken as an axiom that the illuminating value of a mixture of gases was also proportionate to the relation between the carbon and the hydrogen; but although this is very good as a rough criterion in practice, the statement must not be accepted as strictly true. The illuminating power of a mixture of gases is known now to depend far more on *the nature* of the *particular compounds present* than upon the absolute *proportion* between the hydrogen and carbon; for while, on the one hand, it is possible to have a gas (marsh gas) containing as much as 75·4 per cent. of carbon, and yet which is valueless for illuminating purposes, it is also possible to have a mixture of gases in which the percentage of carbon is far less, although the illuminating value is much greater.

Coal gas is found to experience a diminution in its illuminating value by being long stored in holders standing over water, the loss being greater with increasing atmospheric changes. This loss is no doubt due to the partial condensation of such substances as naphthalene and the members of the benzol series, compounds very rich in carbon, and the withdrawal of which from the gas would considerably lower the lighting power. Olefiant gas itself, to which by far the greater part of the illuminating value of gas is due, is soluble to a certain extent in water; acetylene is likewise somewhat soluble in water. It is not therefore surprising that gas should suffer in illuminating value when standing for any length of time over water. The loss is always greater the richer the quality of the gas, but at the same time it is found in practice to be less than might be theoretically expected.

Description and Character of Coals used in Gas Manufacture.—The special varieties of coals which are most used in the manufacture of gas are those belonging to what is termed the bituminous class, and which may be taken to comprise caking coals, parrot coal, and the different varieties of cannel. The value of a coal for gas-making purposes depends not only on the composition of the coal itself, but on the amount of volatile matter which it yields when exposed to heat, and the character of the volatile matter so obtained. Freedom from sulphur is also an important consideration in the selection of a coal for gas-making purposes. The absolute value of a coal can only be determined by experiment, analysis, except in the case of the sulphur, being useful only to a comparatively small extent. The amount of volatile matter which a coal yields is almost a better criterion of value than a knowledge of its ultimate composition. It may, however, be assumed that a first-class gas-making coal should show a fair percentage of volatile matter, associated with a small amount of ash and but little sulphur, while its ultimate analysis should exhibit a comparatively small quantity of oxygen in proportion to the hydrogen. The reason for the last-mentioned consideration is, that when a coal is subjected to destructive distillation, every 16 parts of oxygen present unite with 2 of hydrogen to form 18 parts of water; so that it is only the hydrogen over and above that required by the oxygen that is available for the production of hydrocarbons.

The quantity as well as the quality of gas yielded by each special description of coal is exceedingly variable, and depends much on the temperature employed in distillation; so that the results of different experimenters have exhibited considerable difference. The following table, taken from some experiments made by Mr. BARLOW, may, however, be taken as giving a fair average of the yield of gas from different coals :—

Name of Coal.	Number of experiments, the average of which is taken.	Produce of one ton of Coal,				Equivalent of one cubic foot of gas in grains sperm.	Consumption of gas per hour to give a light equal to twelve standard candles.	Value of the gas from one ton of coals in pounds of sperm.
		Cubic feet of gas.	Pounds of coke.	Pounds of tar.	Pounds of ammoniacal liquor.			
Boghead cannel,	3	13,334	715	733·3	none.	1109·	1·3	2057
Newcastle cannel,	3	9,833	1426	98·3	60·	606·	2·37	851
Wigan cannel—Inch Hall,	3	10,850	1332	218·3	161·6	465·8	3·09	718
Lochgelly cannel,	2	8,331	1245	225·	340·	439·	3·28	522
Mixture of 7-8ths Lochgelly and 1-8th Boghead,	1	9,055	1200	400·	170·	695·	2·07	899
" 9-10ths Lochgelly and 1-10th Boghead,	2	9,050	1205	335·	290·	600·	2·4	774
" 11-12ths Lochgelly and 1-12th Boghead,	1	9,750	1240	227·	270·	443·	3·25	617
Pelton main,	4	9,500	1540	112·5	112·5	311·	4·7	422
Mixture of 3-4ths Pelton and 1-4th Boghead,	3	12,800	1366	206·6	116·6	553·	2·6	1009

Mr. Barlow is of opinion that coals which contain more than 30 per cent. of volatile matter require a higher temperature for their distillation.

As before remarked, the yield of gas will differ with the temperature employed. With good gas coals, however, it is found that the amount of yield is a very fair criterion of actual value, as the following table by Mr. Samuel Hughes will show:—

Description of Coal.	Cubic feet of gas per ton of coal.	Specific gravity of the gas.	Weight of gas in pounds avoirdupois per ton of coal.	Authority.
NEWCASTLE COALS.				
English caking coal,	8,000	·420	257	Dr. Fyfe.
Newcastle coal,	11,648	·675	423	Mr. Joseph Hedley.
Pelaw, Newcastle,	11,424	·444	389	" "
Pelton, "	11,424	·437	382	" "
Blenkinsopp, Carlisle,	11,200	·521	447	" "
Newcastle,	8,500	·412	268	London, 1837.
Wallsend, Newcastle,	12,000	·490	550	Quantity made in the revolving web retort—authority, Mr. Clegg.
Pelton,	11,000	·430	363	Author of the Chemistry of Gas-lighting in the *Journal of Gas-lighting*.
Leverson,	10,800	·425	353	
Washington,	10,000	·430	330	
Pelaw,	11,000	·420	355	
New Pelton,	10,500	·415	335	
Dean's Primrose,	10,500	·430	347	
Garesfield,	10,500	·398	321	
Gosforth,	10,000	·402	308	
West Hartley,	10.500	·420	339	
Hasting's Hartley,	10,300	·421	333	
Blenkinsopp,	9,700	·450	335	
Berwick and Craister's Wallsend,	12,507	·470	449	Mr. Clegg.
Pelaw Main,	12,400	·420	399	"
Russell's Wallsend,	12,000	·418	384	"
Ellison' Main,	11,200	·416	357	"
Felling Main,	11,200	·410	351	"
Pearith's Wallsend,	11,147	·410	350	"
Dean's Primrose,	11,120	·410	349	"
Penton Main,	10,987	·420	337	"
Eden Main,	10.400	·400	318	"
Heaton Main,	10,400	·410	326	"
	9,000	—	—	Average production by the Phœnix Gas Company for the year 1848.
PARROT OR CANNEL COALS.				
Yorkshire parrot,	11,000	—	—	Dr. Fyfe.
Wigan cannel,	9,500	·460 to ·520	357	"
Scotch parrot,	9,500	·640	466	"
Ramsay's Newcastle cannel,	9,746	·554 to ·580	423	"
Lochgelly parrot,	9,123	·567	396	"
Lesmahagow cannel—first experiment,	11,681	·540	483	Mr. Wright.
" " second experiment,	9,878	·650	492	"
Ramsay's Newcastle cannel,	9,016	·604	417	"
" " "	9,333	·598	427	John Kay, Manager of Dundee Gas-works.
" " "	9,667	·731	541	Dr. Leeson, Dr. Miller, and Mr. G. H. Palmer.
Lesmahagow cannel,	11,312	·737	638	Mr. Joseph Hedley.
Welsh cannel,	11.424	·737	645	" "
Wigan cannel,	11,200	·606	520	" "
" "	9,500	·580	422	Liverpool New Gas and Coke Company.
Wemyss cannel,	10.976	·670	563	Mr. Wright.
" "	10,192	·691	538	"

Description of Coal.	Cubic feet of gas per ton of coal.	Specific gravity of the gas.	Weight of gas in pounds avoirdupois per ton of coal.	Authority.
Wigan cannel,............................	9,408	·478	344	Mr. Wright.
Knightswood cannel,......................	9,720	·590	439	"
Boghead cannel,..........................	15,000	·752	866	Mr. J. Evans, at Westminster Station of Chartered Gas Company; mean of three experiments.
Lesmahagow,..............................	13,500	·642	666	" " "
"	13.200	·618	627	" " "
Capeldrae cannel, ...	14.400	·577	638	" " "
Arniston cannel,.........................	12.600	·626	606	" " "
Ramsay cannel,...........................	10,300	·548	433	Mr. J. Evans.
Wemyss cannel,...........................	14,300	·580	637	"
Kirkness cannel,.........................	12,800	·562	552	"
Knightswood cannel,......................	13,200	·550	558	"
Wigan—Ince Hall—cannel,..................	11,400	·528	461	"
Pelton cannel,...........................	11,500	·520	459	Mr. Joseph Hedley.
Leverson cannel,.........................	11.600	·523	466	"
Washington cannel, ...	10,500	·500	403	"
Wigan cannel,............................	14,453	·640	708	Mr. Clegg.
" "	14,267	·610	664	"
Scotch cannel,...........................	14,000	·580	622	"
" "	13,813	·500	529	"
DERBYSHIRE, WELSH, STAFFORDSHIRE, AND OTHER KINDS OF COAL.				
Derbyshire deep main,....................	9,400	·424	308	Mr. Wright.
Brymbo two-yard coal,....................	8.880	·463	315	"
Powell coal—two hundredweight charges every five hours,.....................	10,165	·459	357	"
Powell coal—one and a half hundredweight charges every five hours,...............	8,250	·470	296	"
Bickerstaff—Liverpool,...................	11,424	·475	415	Mr. Hedley.
Neath—South Wales,.......................	11,200	·468	401	"
Birmingham Gas Company—lamp coal from West Bromwich,.......................	6,500	·453	226	Birmingham Gas Company Parliamentary Return.
West Bromwich,...........................	6,500	·455	227	Birmingham and Staffordshire Parliamentary Return.
Macclesfield,............................	6,720	—	—	
Stockport,...............................	7,800	·539	322	Parliamentary Return.
Oldham, Watergate, and Wigan cannel, mixed,	9,500	·534	388	Manchester Parliamentary Return.
Ormskirk, or Wigan slack,................	8,200	·462	290	Liverpool Old Company Parliamentary Return.
Low-Moor, mixed with two kinds of slack,....	8,000	·420	257	Bradford Parliamentary Return.
Leeds coal,..............................	6,500	·530	263	Leeds Company Parliamentary Return.
Cannel and common coal mixed,............	8,000	·466	285	Sheffield Company Parliamentary Return.
Derbyshire soft coal,....................	7,500	·528	303	Leicester Parliamentary Return.
" "	7,000	·448	240	Derby Parliamentary Return.
" "	7,000	·424	227	Nottingham Parliamentary Return.
STAFFORDSHIRE.				
South's,.................................	10,933	·398	333	Mr. A. Wright.
Second variety,..........................	10,667	·395	322	"
Third variety,...........................	10,667	·390	318	"
Fourth variety,..........................	9,600	·320	235	"
Forest of Dean,..........................	10,133	·350	271	"
Second variety,..........................	10,133	.360	279	"
WELSH COAL.				
First variety,...........................	10.000	·385	295	"
Second variety,..........................	10,133	·380	295	"

Some practical gas engineers are of opinion that the quantities in the preceding table are larger than are usually obtained in the works. The following table, by Mr. WRIGHT, in which the results of experiments on the distillation of cannel coals are placed in a very practical commercial form, will be found interesting:

	Name of Coal.						
	Lesmahagow cannel.		Ramsay's Newcastle cannel.	Derbyshire deep main.	Wemyss' cannel.		Wigan cannel.
	Exp. 1. Pounds per ton.	Exp. 2. Pounds. per ton.	Pounds per ton.	Pounds per ton.	Exp. 1. Pounds per ton.	Exp. 2. Pounds per ton.	Pounds per ton.
Coke,..................................	1091·	1064·	1435·	1355·	1124·5	1188·	1326·0
Gas, ...	463·	483·5	410·	300·	551·4	528·	238·0
Tar,...................................	594·	603·	295·	219·	224·0	197·	250·0
Ammonia and water,.....................	4·5	4·5	6·72	179·	—	—	—
Loss,..................................	87·5	85·	93·28	207·	340·1	327·	326·0
	2240·	2240·	2240·	2240·	2240·	2240·	2240·
Cubic feet of gas,.....................	11,680	9,878	9,016	9,400	10,976	10,192	9,408
Specific gravity,......................	0 540	0·650	0·650	0·424	0 670	0·691	0 478
Illuminating power, gas of specific gravity 0·361, being,..	—	2·33	2·	0·8	2·47	—	1·5

The annexed tables, by Dr. Fyfe, contain, in addition to the quantities of gas afforded by the coals, much valuable information upon the relative illuminating values of the gases, which he arrived at by the chlorine test. When chlorine is added to coal gas, it forms with the olefiant gas and vapours of the heavier hydrocarbons—with those constituents, therefore, upon which the illuminating power depends — oily compounds, which separate, and the original volume is consequently diminished. The diminution which the volume of the gas suffers when mixed with chlorine is, therefore, in direct proportion to its illuminating power, and to the value of the gas.

Coals.	Cubic feet of gas per ton.	Comparative value of coals per ton by quantity of gas.	Specific gravity of gas, air = 1000.	Condensation by chlorine per cent.	Duration by jet, five-inch flame. M. S.	Comparative value of gas by chlorine.	Comparative value of gas by durability.	Comparative value of gas by chlorine and durability.	Comparative value of coals per ton, taking quantity of gas condensed by chlorine and durability into account.
English Cannel :—									
Yorkshire,……	11,500	1·28	·451	7·66	45·	0·85	0·92	0·78	1·00
Scotch Cannels :—									
Knightswood,……	8,960	1·00	·557	·9	48·	1·00	1·00	1·00	1·00
Lochgelly,……	9,123	1·01	·567	14·5	65·30	1·66	1·36	1·95	1·11
Marq. Lothian,……	10,000	1·11	·556	13·	60·	1·44	1·25	1·80	2·00
Torryburn,……	11,200	1·24	·624	13·	57·30	1·44	1·19	1·71	2·13
Monkland,……	10,190	1·13	·667	16·	67·	1·77	1·4	2·01	2·29
Arniston,……	10,640	1·18	·637	17·5	68·30	1·94	1·41	2·03	2·41
Wemyss,……	10,080	1·12	·642	19·5	75·	2·16	1·56	2·24	2·54
Kirkness,……	9,620	1·07	·711	20·75	80·18	2·30	1·67	2·40	2·58

This table exhibits the quantity of gas afforded from 1 ton of each variety of coal; the specific gravity of the gas; the amount of condensible matter by chlorine; the durability of the gas when burned by a single jet with a 5-inch flame; the comparative value of the gas for affording light, as shown by the chlorine and by the durability tests, and by both taken together, which, when this test is had recourse to, is the proper method to follow. It shows also the comparative value of the coals for the purpose of illumination by combustion of their gases, as proved by the quantity of gas afforded by each, and also by the quantity and quality taken together:—

Coals.	Cubic feet of gas per ton.	Specific gravity of gas, air = 1000.	Condensation by chlorine, per cent.	Durability by jet five-inch flame. M. S.	Illuminating power, one foot sperm. candles = 120 grains per hour.	Value of one foot in grains sperm.	Comparative value of one foot in grains sperm.	Value of one ton of coals in pounds of sperm.	Comparative value of coals.	Pounds of coke per ton of coal.	Fixed carbon per cent. in coal.	Ashes per cent. in coal.	Pounds of sulphur per ton of coal.
English Coking :—													
Pelton,……	9,746	555	6·5	50·40	3·125	382·2	1·	532·	1·	1,563	—	—	—
English Cannel :—													
Ramsay's Newcastle,……	9,692	625	13·25	60·40	3·33	399·6	1·04	553·	1·04	1,520	—	—	—
Wigan,……	12,010	566	9·9	52·5	3·04	365·4	0·95	627·4	1·17	1,360	55·	7·1	—
Scotch Cannel :—													
Donibristle,……	9,923	593	9·	51·5	7·51	901·2	2·35	1277·5	2·4	1,220	49·22	4·28	8·5
Lesmahagow,……	10,176	669	17·	60·	8·77	1058·8	2·75	1539·5	2·87	1,360	42·44	4·	—
Capeldrae—one,……	11,500	644	18·	65·25	8·312	997·4	2·61	1638·7	3·08	999	33·2	7·7	7·7
Capeldrae—two,……	9,670	650	17·8	73·37	10·01	1201·2	3·24	1670·3	3·18	1,256	23·9	24·5	
Boghead,……	15,426	726	23·37	84·44	10·38	1245·6	3·25	2755·6	4·3	760	9·25	21·7	8·

Coals intended for gas making should be used as speedily as possible, unless great capabilities for efficient storage are under the control of the gas manager. The coals, of whatever character, should prior to use be protected from undue atmospheric influences, and more especially from alternate exposure to sun and rain, as under these conditions spontaneous ignition may not unfrequently occur, and much loss may thus ensue. It has also been found that under the influence of sun and rain many descriptions of gas coal suffer considerable deterioration in their value as gas and coke producers. The loss sustained by ordinary caking coal may in this way amount to 10 per cent. in the course of three months, the subsequent deterioration being, however, comparatively small. There is not much fear of spontaneous ignition occurring if the coals are kept in a covered shed which, while excluding sun and rain, at the same time permits a free circulation of cool air. In order to detect any undue heating in heaps of coals under storage, the plan of inserting long iron rods at different portions of the mass has often been adopted. These rods are withdrawn at intervals, and in the event of the ends being found unduly heated, and the coal consequently in danger from spontaneous ignition, precautions can be taken to prevent any actual mischief occurring. The heating of coals in this way is no doubt due to the oxidation of the iron pyrites which is always present in varying quantity, and which is converted by atmospheric oxygen into sulphate of iron. HUGHES mentions a very curious fact with regard to pyrites in coal. He states that where a large heap of coal has been stored some time, and exposed to the action of the weather, that in course of time the iron pyrites is decomposed, and the sulphur becomes distributed through the heap in regular strata at some distance from each other, the inclination or "dip" being about 30° to the horizon, the strata themselves remaining parallel. It is difficult to account for this singular phenomenon, although the actual accumulation may be accounted for on the principle of what geologists term "segregation."

Having thus given a description of the yields of different varieties of gas coal, we have now to consider the changes suffered by the coal during its destructive distillation.

Distillation of Coal.—A few remarks are necessary respecting the changes which take place during the manufacture of gas by the destructive distillation of coal at a high temperature in closed retorts. The nitrogen which appears as present in the analysis of coal gas is entirely derived from atmospheric air, admitted into the retort during the charges.

The quality and illuminating value of the gas produced from a special description of coal varies much with the condition of the coal at the time of distillation, whether old or recently obtained, whether wet or dry. The temperature at which the distillation is conducted likewise makes a considerable difference in the eventual result. The chief products of the distillation are compounds of carbon and hydrogen; by far the greater bulk of the carbon in the original coal being, however, left behind in the retort as coke. These compounds of carbon and hydrogen are produced in three different forms, viz., gaseous, liquid, and solid. The number of constituent atoms in each compound being, as a rule, comparatively small in gaseous hydrocarbons, more numerous in the liquid, and greatest of all in the solid.

The chemical changes which occur during the destructive distillation of coal are both numerous and interesting; and as a correct knowledge of their nature is of the utmost importance to the manufacturer of gas, we shall here endeavour to give a short account of what takes place in the retort when the coal is subjected to heat.

The greater part of the hydrogen of the original coal passes off, partly in combination with oxygen as aqueous vapour, partly combined with carbon as marsh gas and olefiant gas, together with smaller quantities of acetylene, benzol, and other hydrocarbons, while a portion passes off in the free state. The nitrogen of the coal is evolved, in combination with hydrogen, in the form of ammonia, and combined with carbon to form cyanogen; while the sulphur, which is present in the original coal in the form of iron pyrites, is evolved under the influence of heat in three forms, viz., as sulphuretted hydrogen, H_2S; as sulphurous anhydride, or sulphurous acid, as it is more commonly termed, SO_2; and as carbon disulphide, CS_2. Part of the aqueous vapour evolved from the coal is likewise decomposed by the action of carbon at a high temperature, with formation of carbonic anhydride (CO_2), carbonic oxide (CO), and free hydrogen. As the various gases leave the retort, and the diminution of heat allows mutual chemical affinity to come more into play, a series of recombinations ensue. The ammonia unites with a part of the H_2S, CO_2, and SO_2, as well as the cyanogen, forming the sulphydrate, carbonate, sulphite, and cyanide of ammonium respectively, and these compounds again mutually react on each other, the ammonium cyanide and sulphide forming sulphocyanide, while another portion of the sulphide gives rise to the formation of hyposulphite under the influence of sulphurous acid. Part of the carbon disulphide also, no doubt, enters into combination with free ammonia to form ammonium sulphocyanide.

It is a well known law of organic chemistry that the higher the temperature, and the more advanced the decomposition of the substance, the simpler are the products found. When coal or similar organic substances of a bituminous nature are distilled at a comparatively low temperature, the carbon has a disposition to pass off with but little hydrogen; liquid carbides of hydrogen are formed, and there is much tar and little gas, the latter, however, being very rich. As the temperature rises the liquid hydrocarbons diminish in quantity, while the gases increase; there is more gas and less tar. The heat still rising, the gaseous products become richer in hydrogen and poorer in carbon; light carburetted hydrogen is abundantly formed, until at length, the temperature becoming still more elevated, pure hydrogen alone is evolved, a result which is always observed towards the end of distillation in gas making. The strength of the union between carbon and hydrogen seems to diminish with the increase of temperature. Olefiant gas passed through red-hot tubes, over lime, or in fact over any highly heated surface, deposits a portion of its carbon in the solid form, and is converted into a mixture of marsh gas and free hydrogen. The same thing LEIGH has proved of naphtha, which deposits carbon in like circumstances, and is resolved into simpler products.

When compact masses of coal are thrown in heaps of $1\frac{1}{2}$ cwt. into retorts heated to a bright redness, as is now done, they are exposed to two very different conditions: the surface of the mass, the exterior, in contact with the intensely hot retort, is instantly decomposed and charred; hydrocarbons, as olefiant gas, &c., are eliminated, which also at this temperature are partly decomposed and converted into light carburetted hydrogen and pure hydrogen, with deposition of carbon, which, with some undecomposed olefiant gas and volatile hydrocarbons, pass off from the retort. The interior of the mass, on the other hand, is for some time time exposed to a very moderate heat, and a simple distillation is accomplished; those compounds that are formed at a comparatively low temperature, the heavy hydrocarbons, which would ordinarily be in a liquid state, are eliminated; a portion rising into vapour as it reaches the hotter surface, passes off with the gases formed, and condenses again when it has left the retort in the form of tar; but that portion of the vapour which, in its passage, comes into contact with the red-hot surface of the exterior of the mass and of the sides of the retort, deposits a portion of its carbon, and is resolved into simple compounds, olefiant gas, and volatile hydrocarbons, which themselves partly undergo the change already described. As the heat penetrates to the centre, and a red-hot mass of charred material of considerable thickness comes to surround the decomposing coal within, which happens towards the end of the distillation, the whole of the hydrocarbons, namely, light oils, volatile hydrocarbons, olefiant gas, and even light carbide of hydrogen itself, that are eliminated, are decomposed in passing over such an extent of heated surface, and pure hydrogen is almost alone evolved.

The composition of the evolved gases at different periods of the charge has been investigated by Dr. HENRY, who followed analytically, step by step, the whole course of the evolution of gas. He found that at incipient redness scarcely anything but hydrogen, atmospheric air, and some tar passed off, with hardly any illuminating gas; but that after attaining that temperature iluminating gas alone appeared, and this was composed of a mixture of gases in the following relative proportions:—

Time of collection.	Specific gravity.	Out of a hundred parts of gas from Wigan cannel coal.				
		Chlorine absorbed.	Carbide of hydrogen absorbed.	Carbonic oxide absorbed.	Hydrogen absorbed.	Nitrogen absorbed.
In the first hour,	0·650	13	82·5	3·2	0	1·3
	0·620	12	72	1·9	8·8	5·3
	0·630	12	58	12·3	16	1·7
Five hours after the commencement,	0·500	7	56	11	21·3	4·7
Ten " "	0·345	0	20	10	10	10

As a general result, therefore, "carbide of hydrogen" (which no doubt comprises marsh gas and olefiant gas) is formed in decided excess, and the most luminous portion of this, which is condensable by chlorine, comprises only about one-fifth of the whole. These numbers also prove distinctly that, after about the fifth hour, the quantity of gas only increases, but the quality does not improve; indeed, this deteriorates so rapidly that, at the expiration ten hours, the gas which passes over is hardly of luminous when ignited, but burns with a very faint flame. The specific gravity, as will be seen, keeps pace with the quality of the gas, increasing as the latter improves, and can thus far be taken as a test for its value. As pure olefiant gas has about the specific gravity of common air, 0·98, the density of the illuminating gas must increase with the quantity of the olefiant gas contained in it; yet an extraordinary amount of carbonic oxide, specific gravity 0·97, or of carbonic acid, specific gravity 1·52, may give rise to errors of some magnitude.

MARCHAND'S experiments show very clearly the progress of this decomposition. When olefiant gas was conducted through a red-hot tube and the heat constantly elevated, the gas passing off, collected in successive portions, contained the following quantities of carbon to 100 of hydrogen:—

Hydrogen.	Carbon.	Nature and Temperature of the Gas.
100	614	Olefiant gas.
100	580	Red heat.
100	533	—
100	472	—
100	367	—
100	325	Intense white heat.
100	307	Light carbide of hydrogen.
100	7	Continued white heat, nearly pure hydrogen.

The great increase of hydrogen, which at the last period amounts to 60 per cent., is remarkable, and important to the manufacturer; an augmentation which is no longer due to the decomposition of aqueous vapours but to that of the gaseous hydrocarbons.

It has been estimated by PECKSTON, that when coal is submitted to destructive distillation, the relative quantities of gas given off at different periods of an eight-hour charge, preserving the degree of heat uniform throughout the operation, were as follows:—In the first hour, 20; in the second, 15; in the third, 14; in the fourth, nearly 13; in the fifth, 12; in the sixth, 10; in the seventh, 9; and in the eighth, about 8 per cent. of the whole quantity. The number of cubic feet at the end, therefore, is two and a half times as much as at the commencement. As the quality of the gas, as well as the quantity, decreases as the distillation approaches completion, it follows that the comparative value of the various quantities of gas produced at the different stages of the distillation is even more variable.

The greater the heat employed, then, in the process of gas making, above a certain limit—namely, that requisite for the decomposition of the liquid hydrocarbons—the greater will be the bulk of the gas, and the poorer its quality; the more light carburetted hydrogen, hydrogen, and carbonic oxide it will contain, and the less volatile hydrocarbons and olefiant gas. The analysis of the gas will consequently furnish a test of the excellence of the process employed in the manufacture, and a check on the workman, by exhibiting, in the relative amount of hydrogen and of the illuminating hydrocarbons, whether the heat has been too great. A large quantity of gas may be made from coal, and very badly made. *The mere amount of gas produced is no proof of the excellence of the manufacture.*

Cannel yielding 11,000 feet of gas per ton, of specific gravity 0·600, would furnish for every 100 lbs. distilled, about—

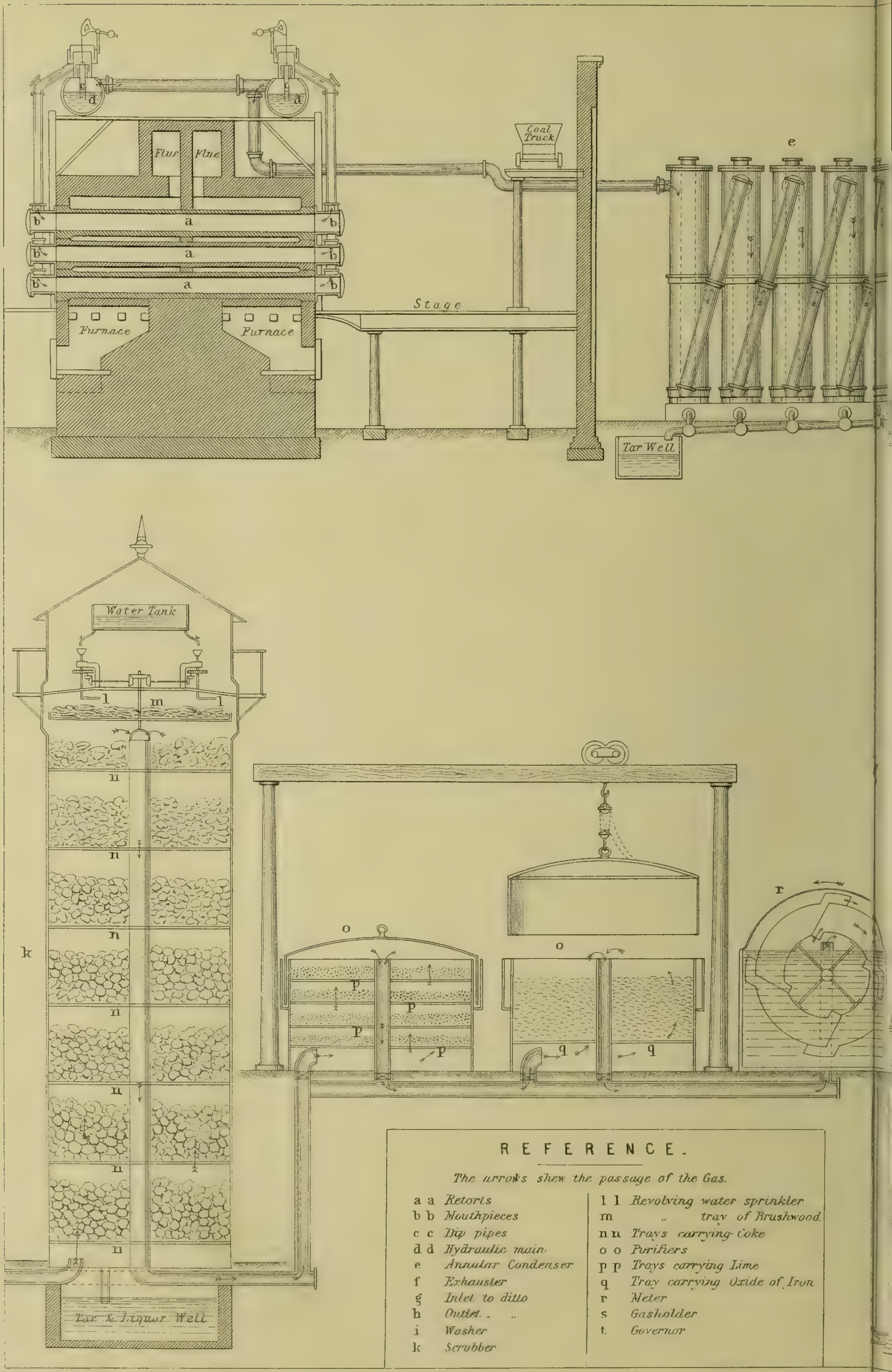
	Lbs.
Gas,	22·25
Tar,	8·50
Ammonia water,	9·50
Coke,	59·75
	100·00

These proportions will vary considerably, but still the numbers will represent a general average of produce. It has been shown above, that considerably more than one-third of the weight of the gas produced is distilled from the cannel in the form of tar, which contains and is almost entirely composed of the richest hydrocarbons; whilst the gas, as it contains only about 45 per cent. of compounds of carbon and hydrogen by measure, amounting to about half its weight, has really only 11 lbs., or something near that number, of hydrocarbons, and of this only about 4 lbs. will be olefiant and richly illuminating gases. So that the tar truly holds as much illuminating matter, or nearly so, as exists in the gas—not, however, twice as much, as would appear from the numbers; for it must be borne in mind that in the oils composing the tar the carbon exists in much greater proportion than the hydrogen—one of the lightest, benzol, being a compound of carbon, 6; hydrogen, 6—naphthalin and the solid carbides being represented by carbon, 10; hydrogen, 8; and even higher proportions of carbon. So that, in the decomposition into illuminating gases, much of the weight must be lost in the form of deposited carbon. It will be now tolerably apparent, that in the form of distilled matters nearly one-half of the illuminating portion derivable from coal and cannel is lost to the gas. It is probable that a perfect system of gas making would produce, from good cannel, a compound containing 20 per cent. of olefiant or other illuminating gases.

Knowing the sources from which the various compounds formed during the process of destructive distillation arise, and knowing the conditions of their formation, the gas manager is in a better position to control the quality and character of the gas which he is manufacturing. Water, producing as it does hydrogen, carbonic oxide, and carbonic acid, should be avoided as diminishing the lighting power of the gas, and it should be an object therefore to keep the coals as dry as possible. The use of wet coal has likewise an injurious tendency in unduly diminishing the heat of the retort. The sulphur compounds cannot well be controlled by any condition of distillation, as the greater portion of the iron pyrites from which the sulphur is derived exist in a fine condition diffused through the bulk of the coal; hand-picking has, however, been sometimes adopted as a means of separating that portion of the pyrites which occurs in comparative large masses, and of thus avoiding the excessive production of sulphur compounds. The production of carbon disulphide in comparatively large quantity is, undoubtedly, in the main due to the employment of abnormally high temperatures, and to the irregular heating of the retorts, under which conditions some of the retorts in a setting have their charge worked dead off, before the contents of the remainder have yielded up all their gas. When this occurs the charges of those retorts which have been exposed to the highest temperature are being subjected to a more or less prolonged roasting, by which that portion of the sulphur which would have remained behind in the coke, if the charge had been withdrawn as soon at is was spent, becomes united with carbon, and passes off as carbon disulphide.

Comparative Cost of Gas and other Sources of Artificial Light.—There has often been considerable doubt in the public mind as to gas being the cheapest material for artificial illumination; a careful consideration of the subject will, however, show that gas at a moderate price will compare favourably, not only in economy, but in convenience, with all other materials used for artificial illumination. Of all substances which are used as light producers, ordinary varieties of paraffin oil burnt in well constructed lamps give a light which, in point of economy, most nearly approaches that obtained from coal gas.

In comparing the cost of gas and oil, it must not be forgotten that the conditions under which they are burnt for domestic purposes are, as a rule, totally dissimilar. In the case of lamps consuming oil of whatever description, a single one is generally used in a room, emitting a light seldom exceeding from 7 to 10 candles; with gas, however, it is usual to consider a two or even three light gasalier as necessary for proper illumination, and allowing each burner to give a light of 10 candles, an extremely moderate estimate, the total light would be double or treble that obtained from the lamp. A further point for consideration is that where a source of light such as gas is provided all over a house, lights are used as a matter of convenience in places which with a less convenient source of illumination would only be lighted where absolutely necessary. Thus, in estimating the comparative cost of gas and oil, people are but too apt to overlook the far greater amount of light usually obtained from the former means of illumination, forgetting the fact that for a test to be *truly* comparative, it must be based on the cost of material for producing *equal quantities of light*. Another objection which has been raised to the use of gas, is that its combustion vitiates the air more, and occasions greater heat than the combustion of oil or candles. The combustion products are, however, much the same for gas as for oil, the only difference being that gas, when burnt, in addition to other products yields small quantities of sulphurous acid. It is far more probable that the vitiation and heating of the air during the combustion of gas is due to the increased amount of material consumed, more carbonic acid and water being produced, a greater degree of light being naturally attended with increased atmospheric vitiation and greater heat. The following table by Dr. LETHEBY will show the comparative cost of gas and other sources of artificial illumination:—

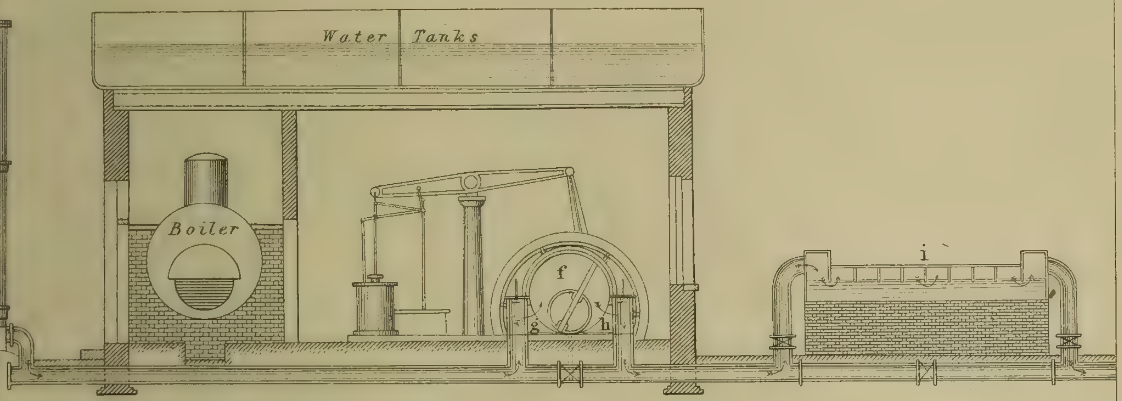


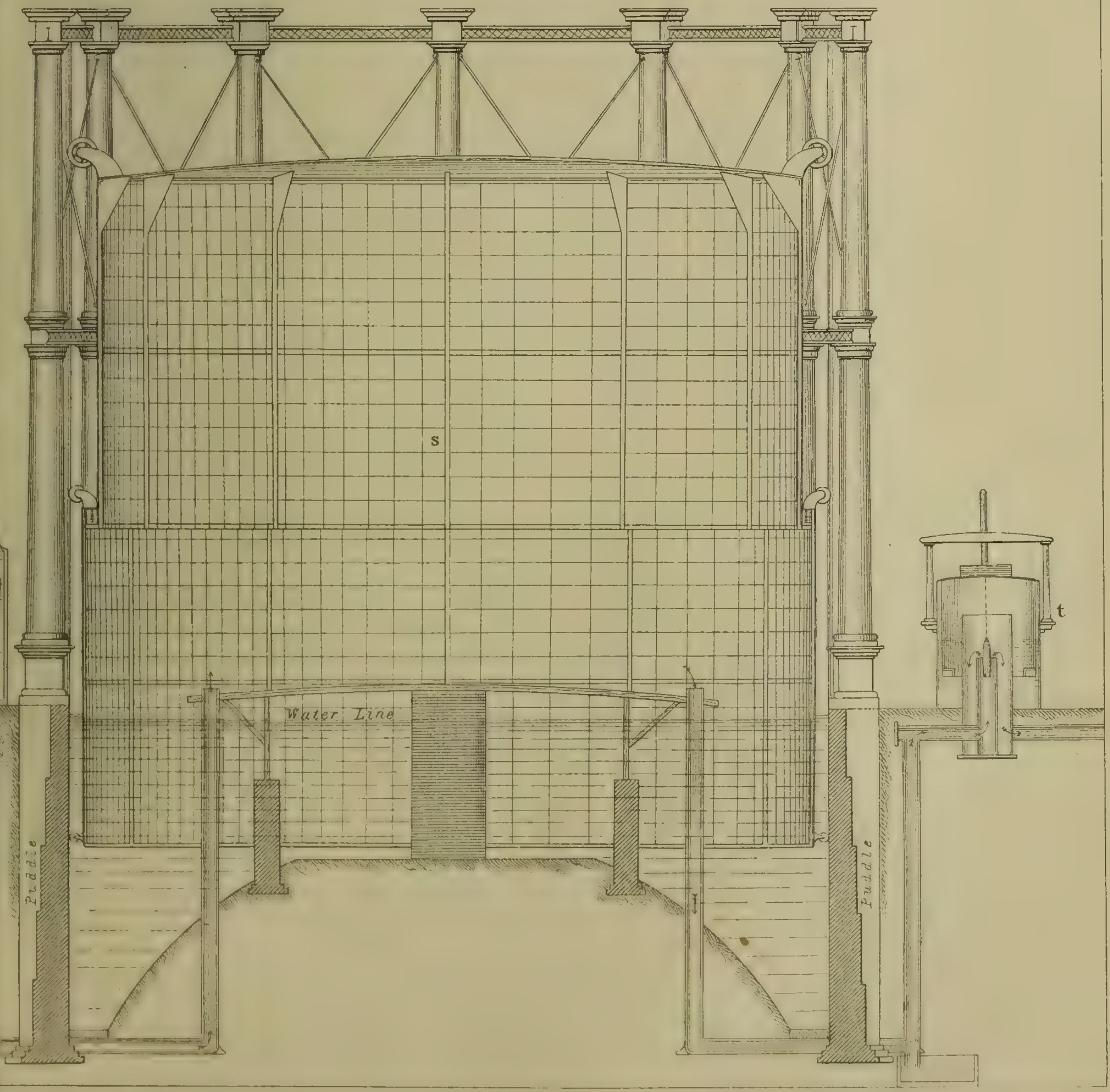
REFERENCE.

The arrows shew the passage of the Gas.

a a	*Retorts*	l l	*Revolving water sprinkler*
b b	*Mouthpieces*	m	„ *tray of Brushwood.*
c c	*Dip pipes*	n n	*Trays carrying Coke*
d d	*Hydraulic main*	o o	*Purifiers*
e	*Annular Condenser*	p p	*Trays carrying Lime*
f	*Exhauster*	q	*Tray carrying Oxide of Iron*
g	*Inlet to ditto*	r	*Meter*
h	*Outlet* „ „	s	*Gasholder*
i	*Washer*	t	*Governor*
k	*Scrubber*		

J. B. LIPPINCOTT





CO. PHILADELPHIA.

Gas at 4s. 6d. per 1000 feet taken as,		1
Sperm oil burnt in Argand (8s. per gal.),		8
Mould tallow candles of six to the lb.,		12
Sperm oil burnt in open lamp,		17
Sperm candles of six to the lb.,	at 2s. per lb.	24
Composite candles of six to the lb.,		29
Wax candles of six to the lb.,		30

The numbers show that, to obtain the amount of light afforded by a quantity of gas costing, say, one shilling, the cost of material for obtaining an equal amount of light from others sources would vary from 8s. up to as high as 30s. Lewis Thompson has likewise calculated the amount of various light-giving materials necessary for affording an equal degree of illumination, and from his figures the relative cost may be readily deduced.

1000 feet of common thirteen candle gas were found to equal the light afforded by		$44\frac{4}{7}$ lbs. of sperm candles.
"	"	$48\frac{3}{8}$ lbs. of carefully snuffed wax candles.
"	"	$50\frac{1}{7}$ lbs. of stearic acid candles.
"	"	$52\frac{9}{10}$ lbs. of best mould candles.
"	"	$54\frac{3}{7}$ lbs. of best dip candles.
"	"	$6\frac{1}{2}$ gals. of purified colza oil, specific gravity, 0·915.
"	"	$5\frac{9}{10}$ gals. sperm oil, specific gravity, 0·888.

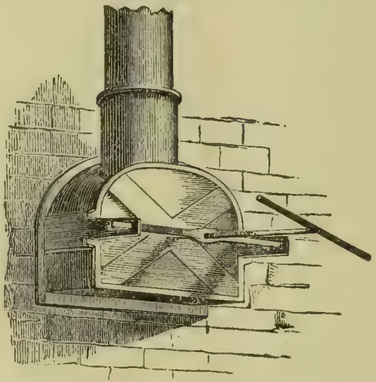
At the present time these figures would calculate to somewhat increased quantities, as the improvements which have been made in gas burners would enable the then 13-candle gas to give the light of nearly 16 candles, thus increasing the equivalent amounts of other materials by about one-fourth.

General Description of Gas Manufacture.—In the manufacture of gas by the ordinary method the coal is placed in charges of from 2 to 4 cwts. at a time in iron or clay vessels, termed retorts, which are previously heated by means of a furnace to a suitable gas-making temperature. Retorts are now most usually made of fire clay, and the exact temperature to which they are heated prior to the introduction of the coal varies at different works from a cherry-red to a heat bordering on whiteness. A full cherry-red heat is, however, considered to be the best temperature for the carbonization of the ordinary varieties of gas coal. The charge is allowed to remain in the retorts for a period of from four to six hours, at the expiration of which time the coal will have yielded up all its gas, and have become converted into good saleable coke. Each furnace is made to heat a number of retorts, usually in settings of five or seven. The gas, as it comes from the retorts, passes up through a pipe placed near the mouthpiece, called the ascension pipe, and is conducted by this into the hydraulic main, where a portion of the tarry matters becomes deposited. The hydraulic main extends along the whole length of the retort house, receiving the dip pipes of successive benches of retorts in its passage. The object of the hydraulic main is twofold—it acts in the first place as a means of conveying away the gas from the place where it is generated, and in the second place, being always about half full of tar and ammoniacal liquor, into which the terminal pipes from the retorts dip, it acts as a contrivance for sealing the pipes, and thus preventing any escape of gas during the drawing and charging of the retorts. The gas is conducted after leaving the hydraulic main to the condenser, where, by traversing a series of pipes exposed to the cooling action of the air, the gas becomes cooled, and deposits the tar and aqueous vapour previously held in suspension. The tar and liquor deposited by the action of the condenser are run off by a suitable pipe into a receptacle called the tar well, the capacity of which must be proportionate to the amount of coal carbonized. The tar well forms the reservoir from which the tar and liquor are periodically pumped up for sale. From the condenser the gas passes to the exhauster, whose function is to remove the gas from the heated retorts as fast as it is produced, and at the same time to propel it onward with sufficient force to enable it to pass through the materials used in purification, and from thence to the holder. It is necessary to remove the gas quickly from the retorts, in order to reduce the pressure as much as possible; any pressure on the retorts results in a partial decomposition of the richest portions of the gas, and consequent loss of illuminating value. Also if the gas has to leave the retort under pressure considerable leakage will ensue through the walls of the retort and the various fittings. From the exhauster the gas either enters the scrubber direct, or in works where washers are likewise employed, passes into the latter vessels first. The function of both washer and scrubber is the removal of ammonia and part of the sulphuretted hydrogen from the gas, which is effected in the washer by bubbling it through water, and in the scrubber by bringing the gas into contact with a large extent of surface kept wet by water. The last named vessel is most complete in its action, and removes all but a mere trace of ammonia from the gas. The gas then passes to the purifiers, a series of vessels charged with lime and oxide of iron, by the action of which the remaining impurities, consisting of carbonic acid and sulphuretted hydrogen, are removed from the gas, which is then in a sufficiently pure condition to be supplied to the consumer. After having passed through the purifiers the gas is conducted to the station meter, where the amount of the daily make is registered, and from thence the gas enters the holders, where it is stored until required for use. An apparatus termed a "governor" is used at the outlet of the holder, in order to regulate the pressure at which the gas is allowed to pass into the street mains for the consumer (see Plate I.).

Retorts.—The retort and its setting may justly be considered as *one* of the most important, if not *the* most important, of the various parts of the plant of a gas works, as upon the work of the retort house depends not only the yield of gas obtained per ton of coal, but likewise, in a great measure, the actual quality of the gas produced.

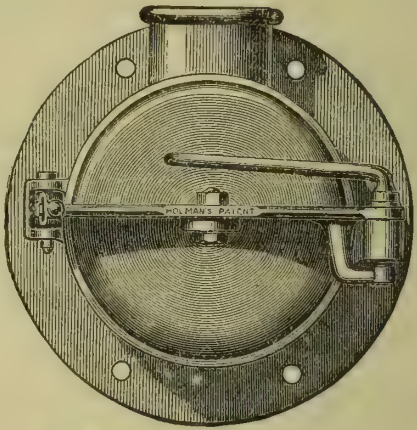
Retorts were formerly constructed of iron, but these have latterly been almost entirely superseded by those made of fire-clay, which, while cheaper in the first instance, admit of a temperature being used which would prove rapidly destructive to such an oxidisable metal as iron. Clay retorts have also the advantage of retaining the heat better; and owing to their being but slow conductors of heat, the introduction of the charge does not produce the same lowering of temperature that is found to take place in the use of iron retorts. The "life" of a clay retort, or the time which it will last in active work, is about three years, while an iron retort seldom lasts more than a year. At the same time, the latter is still valuable as old metal after becoming otherwise useless, whilst a clay retort, after it has become thoroughly worn out, is practically worthless.

Fig. 1.



Retorts as now used are of two kinds—viz., those termed "single," which have an average length of about 8 feet 6 inches, with an internal diameter of about 14 inches, and those termed "through," which with the same internal diameter have a length of from 18 to 20 feet. The "single" retorts have one end closed, the other end having a mouth-piece, while through retorts have a mouth-piece at each end. In setting the ordinary clay retorts, there are several ways adopted, the most usual methods, however, being that of either building the retort in sections, constructing the retort entirely of fire-bricks made for the purpose, or, lastly, in the case of single retorts, having them ready made in one entire piece, which is strengthened during setting by a surrounding of fire-bricks, in order to give more solidity to the general structure. The mouth-piece of the retort, Fig. 1, through which the charge is introduced and withdrawn, is invariably constructed of iron, being attached to the retort by means of iron bolts and cement. The mouth-piece carries the ascension pipe, which is fitted to it by means of a socket joint. The front of the mouth-piece is fitted with a lid of wrought or cast iron, and which is made by suitable means to fit gas-tight. In the ordinary lids a gas-tight joint is obtained by means of luting, the lid itself being pressed down tight into the retort mouth by a screw and cross bar. In a variety of lid which, from its greater convenience, has come much into use of late, a gas-tight joint is obtained by making the metal surfaces of the mouth-piece and lid so true that the pressure of a lever insures a perfectly gas-tight union. This form of retort lid moves on a hinge, so that it is never removed from the mouth-piece. The Morton lid, as this description is termed, is shown in Figs. 2 and 3, and the ordinary cast-iron lid in Fig. 1. To the upper surface of the iron casting forming the retort mouth is fitted the stand pipe, or ascension pipe, as it is more commonly called. Its diameter varies from 3 to 6 inches, and it extends upwards to a height above the level of the retort bed, where it is connected with a curved pipe known as the "bridge pipe," to the other end of which is fitted the "dip pipe," which enters the hydraulic main, and is the point at which the gas finally escapes from the retort. Retorts are usually set in groups of three, five, seven, eight, or nine to a bed. The shape somewhat varies, but that usually adopted is either the round, the D, or a setting containing both.

Fig. 2.



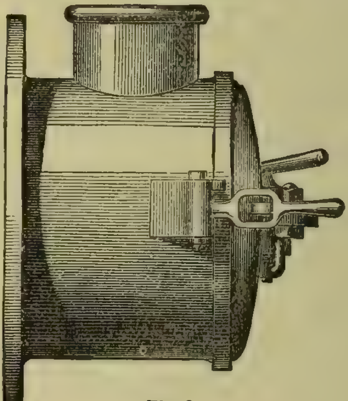


Fig. 3.

Each group, or "setting," of retorts, as it is termed, is heated by a separate fire, and admits of control of temperature by means of separate dampers. All the furnaces in a bench are connected to one flue, which leads to one or more chimney shafts, in order to carry away the products of combustion. The beds of furnaces are constructed of fire-bricks, the most infusible being selected for the inner parts of the furnace most exposed to heat. An outer casing of common brickwork is generally used for the double purpose of preventing loss of heat by radiation and imparting greater strength to the general structure; and in order to impart still greater strength, the brickwork is surrounded by buck-stays, which are iron bands extending across and around the retort benches. The furnace itself is so constructed, that while of sufficient solidity to impart permanence to the setting, there is a sufficiency of suitably arranged hollow spaces, or "nozzles," to allow the heat to communicate to the retorts in the most advantageous manner; and the heat is retained as far as possible by making the flame and products of combustion perform a circuitous route round the retorts prior to their final exit by the flues. The exterior walls are, at the same time, sufficiently thick to retain the heat and prevent undue loss by radiation. Where coke is used as a fuel, the area of the fire-place should be small in proportion to its depth, in order that the air may have a good depth of fuel to pass through; carbonic oxide is thus produced, which, forming a flame of great heating power, insures greater economy as well as uniformity in the heat of the retorts.* Beneath each fire is an ash pan, which is best constructed of wrought iron. Its office is to retain the ashes and small cinders which are continually dropping through the furnace bars; and it is always kept partly filled with water, the steam from which exercises an important function in keeping the furnace bars from becoming excessively heated. The aqueous vapour passing up continually through the incandescent fuel becomes decomposed, with production of carbonic oxide and hydrogen, which combustible gases no doubt assist in the even heating of the retorts. In spite of all precautions the bars of the furnace are rapidly destroyed, and require renewal about every month.

The number of beds or settings to a bench, and the size of the retort house, vary with the size of the works and make of gas. It is now most customary, in all works of any magnitude, to build retort houses with a stage, that is, in such a way that there are two levels, from the upper of which the retorts are drawn and charged, while the lower receives the coke, which, on being withdrawn from the retorts, falls through an opening in front of the settings, and is quenched by men below. The lower level of the retort house thus acts as a coke store, effecting an economy of space. In some works the furnaces are likewise charged from the under level of the retort house, as shown in Plate I. For charging the retorts, shovels are used in small works, but in large works a large scoop is invariably used for the purpose. The ordinary scoop is semicylindrical in shape, and its length is about 6½ to 7 feet, with a diameter of 1 foot; but the actual size varies somewhat with the amount of the charge and size of retort. In the charging of through retorts the scoops used are invariably longer than those used for singles. In charging by the scoop three men are required, one of whom takes the cross handle, and the other two lift the opposite end by means of a bent bar of iron, termed a bridge, and guide the scoop into the mouth of the retort; the scoop is then pushed into the extreme end, inverted, and quickly withdrawn, leaving the coal in a comparatively even layer on the bottom of the retort; this is repeated if necessary, and the mouth of the retort is then quickly closed by means of its lid, previously luted or otherwise, according to the description in use. The whole operation can be performed in ordinary works, according to CLEGG, in about forty seconds.

In drawing the retorts the lid is first somewhat loosened and a light applied, as if this precaution were neglected an explosion, technically called by the workmen "a rap," would occur. The lid is then removed, and the coke withdrawn by means of long rakes, causing it to fall from the retorts either into the coke vault beneath, or into trucks placed for its reception. The rakes used are generally made of three-quarter inch iron rod, and are about 12 feet long, having a handle at one end, while the other extremity, with which the coke is withdrawn, is flattened and bent at right angles to a length of about 6 inches. In the drawing of through retorts the rakes used are somewhat larger, and the drawing, as well as charging, takes place at each end simultaneously, by separate gangs of men. In drawing and charging retorts in large works it is customary to divide the men into gangs numbering five each, three men being employed to charge and draw, termed stokers, one whose duty is to attend to the furnaces, while the fifth quenches the hot coke by means of water; and where there is no coke vault, wheels the coke from the retort house in a barrow. The number of mouth-pieces allotted to each gang is from forty-two to as many as fifty-six.

At the end of the work of each gang of men the furnaces are raked out, the furnace bars freed from slag, which is, where coke is used, considerable, and the furnace itself is then filled up with fresh coke, which rapidly ignites from the heat of the surrounding brickwork. By this means the furnaces are always kept in good condition, and an efficient draught kept up. About once in every month the retorts have to be "scurfed," as it is termed, that is, freed from the deposit of carbon which is continually accumulating. This is sometimes accomplished by at once attacking the deposit by means of chisel bars; as, however, the deposit is exceedingly hard, and there is thus a risk of damaging the retort in the force necessary for removing the carbon, it is better to adopt the plan of loosening the retort lid, and thus allowing the oxygen of the air to burn away the deposit until it becomes sufficiently thin to be manageable. Clay retorts require scurfing about once a month, while iron ones will work for a much longer period without requiring attention; which ever kind of retorts are being used, however, they should never be allowed to continue working too long without being scurfed, as the deposited carbon becomes more difficult to remove the longer it is allowed to accumulate. It likewise considerably impedes the proper heating of the retort. With regard to the work of drawing and charging retorts the men acquire great dexterity by continued practice, the average time occupied for a bench of seven being about twenty minutes, while the average amount of coal carbonized per man amounts, according to Clegg, to as much as 5 or 6 tons a day in well-conducted works; in smaller works, however, it is probable that the work done would be considerably less.

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* With regard to the amount of fuel used, it is generally reckoned that for moderate-sized works about one quarter or 25 per cent. of the coke made is used under the retorts.

The Hydraulic Main, shown at *d* in Plate I., may be described as a large pipe, set perfectly level, and extending the whole length of the retort benches, and receiving the dip pipes from the different benches of retorts in its passage. It is either square, D-shaped, or round, and is usually supported above the retort bed by means of brick piers placed at suitable intervals. The hydraulic main is always about half full of tar and ammoniacal liquors, by which the ends of the dip pipes from the various benches of retorts are sealed, and the gas thus prevented from escaping during the intervals of drawing and charging.

The length of the dip-pipes should not be less than 3 feet, and they are frequently made as much as 5 feet.

Each length of the hydraulic main is usually provided with a partition, the top of which is level with the surface of the fluid, and the object of which is to keep it to the same height in every part of the main. It follows that, where so much depends on the effective sealing-up of the ends of the dip-pipes, every care must be taken to fix the apparatus in a perfectly horizontal position, from end to end. When the hydraulic main is cast iron, the holes to receive the ends of the dip-pipes are cast in it, and the flanges of the same are secured to the main by nuts and bolts, the joints being made with the usual cement, such as that employed for attaching the mouthpieces to the retorts. When the main is of wrought iron, the top is formed by a flat piece, to which the wrought-iron circular part of the main is attached by rivets, and in this flat piece the holes for the dip-pipes are cut by hand. One end of the hydraulic main is closed by a plate having the same section as the outside flange of the main, to which it is bolted and secured by iron cement. A similar plate is also bolted at the other end of the main, but this plate is provided with an orifice usually about half the diameter of the main itself. The lower part of this orifice is immediately above the level of the fluid in the hydraulic main, and the orifice itself corresponds with the exit-pipe, which conveys away the gas to the condenser. The flange of the exit-pipe is bolted on to the perforated end-plate of the main. It is usually provided, soon after leaving this apparatus, with a descending pipe to carry off the tar into the cistern below the condenser. The lower end of this descending pipe must be sealed either by its dipping several feet into the tar of the cistern, or into a small vessel which communicates with the latter. The descending pipe to carry off the tar is not absolutely necessary at this place, because the same office is sometimes performed by the siphon-pipe at the first bottom bend of the condenser.—Hughes.

It is considered desirable by some gas engineers to allow the gas to remain as long as possible in contact with the tar, and for this purpose the end of the hydraulic main is sometimes connected to a pipe of suitable diameter, which returns back along the inside or outside of the retort house, the tar and gas thus flowing along together for some distance before finally separating. The temperature of the gas becomes thus somewhat more reduced prior to its entering the condenser. By the adoption of this plan it is claimed that a larger amount of naphthalene, as well as of carbon disulphide, is removed from the gas, while at the same time the gradual nature of the condensation tends to prevent the undue separation of these volatile hydrocarbons, to the presence of which much of the illuminating value of gas is due.

The Condenser.—From the hydraulic main the gas passes to the condenser, the function of which is to reduce the gas to a normal temperature, at the same time effecting the agglomeration and precipitation of the minute suspended particles of tar and water which are contained in the crude gas. The condenser is essentially a contrivance for causing the gas to traverse a series of pipes, which are kept continually cool, either by being so arranged as to permit a free circulation of cold air, or by being immersed in cold water. The former of these plans is that which is usually adopted as being most convenient. The water condenser as used at the works of the South Metropolitan Gas Company consists of a series of pipes, which are placed horizontally in a vessel of water, the vessel being intersected by partitions in such a way as to insure an even flow of water throughout. In an arrangement of this sort great care is required in the distribution as well as in the rate of flow of the water, as the condensation might otherwise be too sudden, a result which should always be avoided, as possibly effecting a loss in the illuminating power of the gas by the excessive removal of volatile hydrocarbons. The most usual form of condenser in which the condensation of the gas is effected by the cooling action of the air is that represented in Plate I. It consists of a series of large pipes set vertically, and through which the gas passes in rotation. A smaller pipe (the top of which is seen projecting in the Plate), open at both ends, passes up through the centre of each of the large vertical pipes, the gas passing through the annular space between the two pipes. By this means not only is there an *external* cooling surface exposed to the air, but there is likewise a constant current of cool air passing upwards through the smaller central pipe, and the condensation is thus very efficient. Each pipe of the condenser has its separate box at the extreme base for the retention of the deposited liquids, each box having also a separate pipe by which the tar and liquor are conducted away to the tar well. It will be seen by reference to the Plate that the condenser pipes are connected by smaller pipes which lead from the lower part of one to the upper part of the next, so that the gas is made to *descend* each condenser pipe, being thus in a contrary direction to the ascending current of air. This form of condenser is a modification by Wright of the original one introduced by Kirkham. In a still more recent modification by Messrs. Walker, the construction is somewhat simplified and the cost lessened by the use of wrought-iron pipes instead of cast, each pipe being manufactured and put up in one piece. Wrought iron being thin in comparison to the cast material, allows of a more rapid radiation of heat, and consequently more efficient condensation. It is customary in some works to allow small streams of water to trickle over the external surface of the condenser pipes, and the cooling action produced by the evaporation of the water materially increases the efficiency of the condensation. With regard to the *extent* of cooling surface necessary to reduce the gas to a normal temperature, much will depend on the conditions of manufacture; such as the heat at which the retorts are worked, and the arrangement and position of the hydraulic main. According to Hughes, it is sufficient to have 4 feet of superficial area per 1000 cubic feet maximum daily make; but the author of the "Treatise" lately published in the *Gas Journal* gives from 6 to 9 feet superficial as necessary. One thing, however, is certain, viz., that condensation should always be *thoroughly efficient*, and any error should be therefore on the side of a slight excess.

The Exhauster.—This apparatus has now become an indispensable item in the plant of a gas works, in order to prevent the excessive deposition of carbon in the retorts. From the time when the utility of a system of exhaust was first demonstrated by the original experiments of Mr. Grafton in the year 1839, up to the present moment, various machines have been contrived for effecting the exhaustion of the gas. One of the earliest contrivances for this purpose consisted of a series of three small holders partly immersed in water, each of which was alternately raised and lowered in rotation by means of a crank motion, the gas being thus alternately drawn in and expelled. The forms of exhauster now in use are those known as Jones' and Beale's; and there is also a further contrivance known as Korting's steam jet exhauster, the action of which is entirely different to the two preceding forms of machine. The variety of exhauster invented by Mr. Jones was formerly in very extensive use, and its construction will be best understood by reference to Fig. 4.

The two cams are made with their surfaces as true as possible, so that they are in intimate contact at all parts of their revolution, and an equal rate of rotation in opposite directions is given to them by means of attached cog-wheels. The gas is thus drawn in at A, and subsequently expelled in the direction of the arrows.

Beale's exhauster, which is now more extensively in use than any other description, is shown in Figs. 5 and 6, which give a sectional view of the machine, and also a side elevation. A cast-iron case of cylindrical form, and having an inlet and outlet pipe attached, has within it a smaller cylinder, A, the shaft of which is mounted eccentrically with respect to the outer casing. This shaft passes through a stuffing box, and is connected with a driving pulley. To the opposite sides of this inner cylinder are attached two sliding plates or pistons, which when fully extended divide the case of the exhausting vessel into two parts. As the inner cylinder is made to revolve the plates slide in and out, so that the extreme ends are always in contact with the inner side of the external case, and thus the gas is continuously drawn in on the one side and expelled on the other. The machine is generally used at a high speed, and is exceedingly effective, as well as even in its action. It is stated that as much as 70 to 80 per cent. of the effective power can be utilized; while, according to Clegg, a machine 4 feet in diameter is capable of passing as much as 140,000 feet of gas per hour. The exhauster, as well indeed as all other portions of the plant of a gas works, should have a bye pass between its inlet and outlet pipes in case of any accident or obstruction, and it is customary to so regulate the speed of exhaustion to the rate at which the gas is being produced that a water-gauge stands at about 2 inches of vacuum. In many works there are automatic contri-

Fig. 4.

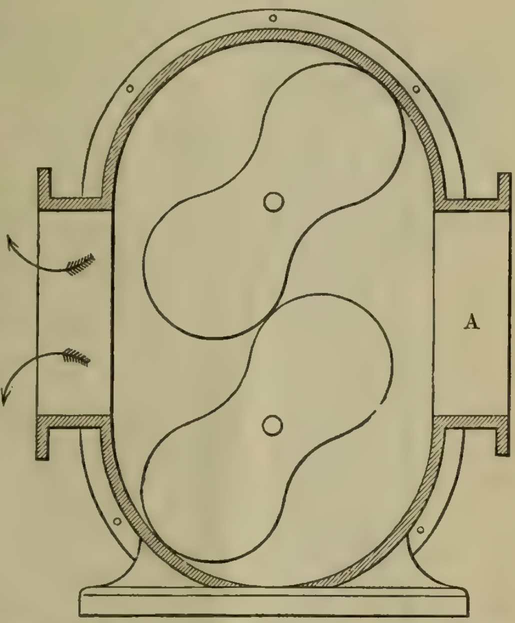


Fig. 5.

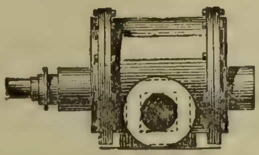
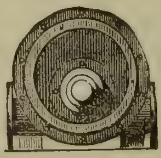
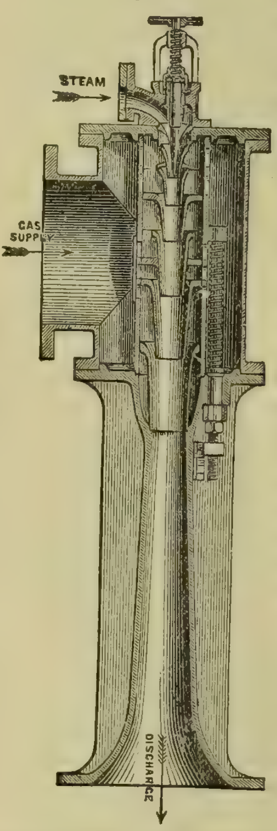


Fig. 6.



vances by which any variation in the pressure of the gas from a certain amount is immediately compensated for, either by having a bye-pass which is more or less opened or closed by means of a throttle valve, or by a contrivance which effects the regulation by an automatic alteration in the speed of the exhauster itself. The last improvement in exhausters lies in a different direction altogether from those previously described, the exhaustion being effected on much the same principle as the Giffard Injector. Korting's Steam Jet Exhauster is represented in the adjoining diagram, which is so simple as hardly to need further explanation. The most economical results have been obtained with steam at a comparatively high pressure, such steam giving greatly increased power with very little increase of heat. This form of exhauster is already largely in use in Continental works, and is found to be exceedingly even in its action, while the comparative simplicity of construction and freedom from mechanical working parts are merits of no small value. It was at first feared that the steam which is introduced into the gas during the action of the machine would by condensation furnish an undue quantity of weak ammoniacal liquor; but this has not been found to be the case, as a comparatively small quantity of high-pressure steam will perform a large amount of effective work. There seems every probability of this form of exhauster coming into more extended use.

Fig. 7.



The Scrubber and Washer.—From the exhauster the gas passes to the washer or the scrubber, the functions of both of which are to remove the ammonia, and at the same time furnish a liquor sufficiently strong to be of commercial value.

The comparative merits of washers and scrubbers has been a much disputed question, some advocating the former and some the latter; there is, however, but little doubt that for the *complete* removal of the whole of the ammonia from the gas the scrubber alone is efficacious, the washer, even in its most complete form, not being so thorough in its action. The only form of washer which merits notice here is that of Mr. George Anderson. This may be briefly described as a vessel having a series of shallow trays charged with water or weak liquor. The gas is made, by an arrangement of partitions, to bubble through the contents of the trays in rotation. The actual construction will be seen by reference to Plate I.; one tray only is, however, there shown, whereas in practice it is customary to employ a series. Washers are not so extensively used as scrubbers for the removal of ammonia. Of the last named vessels there are two descriptions in general use, viz., the Mann scrubber and the Livesey scrubber. Of these two the former is most extensively used, and is that which is represented in Plate I. The Mann scrubber is essentially a circular vessel built up of plates of cast iron bolted together, the whole structure being supported on a brickwork foundation. The size is usually so proportioned that the diameter is about one-third of the height.

Within the scrubber is a series of trays which support layers of coke, while at the extreme top is a contrivance for distributing water or weak liquor, by means of revolving arms perforated with small holes, the motive power being imparted by means of a cog-wheel and shaft connected with a small steam engine. In order to occasion a still further distribution of liquid, the water or weak liquor distributed by the perforated revolving arms falls into a layer of brushwood, which is also sometimes made to revolve, and thus the liquid finds its way on to the first layer of coke in the form of fine drops. The liquid, water or weak liquor, as the case may be, then falls slowly through from tier to tier, becoming stronger and stronger as it descends; the final strength of the liquor depending on the height of the vessel and the amount of water used in the first instance.

The Livesey scrubber differs from that of Mr. Mann chiefly in having an arrangement of deal boards in place of coke. Using Mr. Livesey's own words, which we quote from the *Gas Journal* of October 13, 1874—"The boards are cut from deals or planks 9 or 11 inches wide, 3 inches thick, with nine deep cuts dividing them into ten thin boards, each about a quarter of an inch thick. The small upright blocks which are nailed between the boards to keep them a proper distance apart are 1 inch by half an inch, while to keep each tier separate from those above and below it, and to serve also as sleepers or joists, I use pieces 1½ or 2 inches square. With this plan care must be taken to prevent the gas going up all in one place; and to attain this, I fix a sort of inverted trough made of inch and a quarter boards, which covers the inlet and extends across the bottom of the scrubber. The gas escapes from this trough through a number of small apertures in its sides, and is thus distributed with sufficient uniformity. . . . The fitting of the boards is now proceeded with. The first tier is laid on the bottom of the sieves which used to carry the coke, and tier above tier is fitted until the vessel is nearly half filled; a space is then left about 2 feet 6 inches, when another succession of tiers is laid, which fill the remaining half, and on the top is placed a coarse cocoa-nut matting to spread the water." From the observations of the *Gas Journal* it would appear that Mr. Livesey's mode of operation is to use three scrubbers, the first two being supplied with the liquor from the last in the series, mixed with the condenser liquor, while the vessel through which the gas last passes is supplied in the proportion of 5 or 6 gallons per ton of coal carbonized. The strength of liquor eventually produced is equal to about 10 or 11 ozs.

The special advantages claimed for the Livesey scrubber over that of Mr. Mann are, that the entire structure is lighter, thus requiring a less solid foundation; that it occasions no "back pressure;" and, finally, that when once put up the internal structure of boards does not require periodical renewal, as is the case when coke is used as the charging material.

In the ordinary forms of scrubber coke is generally used for charging, although other materials—such as drain pipes, bricks, tiles, and other substances of a porous nature—are sometimes employed. The divisions of the scrubber are generally of wrought iron, although sometimes constructed of wood. As used by Mr. Mann at the City of London Gas Works, the scrubbers were 28 feet in height and 12 feet in diameter, the tiers of coke being three in number, and each tier having a depth of 8 feet. Water was employed at the rate of 10 gallons to the ton of coal, the strength of liquor being—at the bottom of the first tier, half an ounce; at the bottom of the next tier, 2½ ozs.; while by the time the liquor reached the extreme base it became of 14 ozs. strength. These figures show how rapidly the ammonia is absorbed from the gas by the action of water, by far the greater part of the ammonia being removed before the gas reaches the second tier of coke. By increasing the height of the scrubber, it is possible to make exceedingly strong liquor; but in the majority of cases where the liquor is sold by the gas company to a manufacturer of ammonia salts there is a disadvantage in excessive strength, part of the ammonia being lost during transit owing to its volatile nature.

Mr. Mann states, that with careful working the coke does not require renewal more than once in three years; it is, however, obvious, that unless the condensers are acting efficiently a small quantity of tarry matter would pass on to the scrubbers, and so occasion a partial or complete stoppage. It is customary in many works to pump the liquor up again, using a series of scrubbers; as, however, it is not only possible but easy to procure liquor of the necessary strength by proportioning the height of scrubber and supply of water to the make of gas, it is difficult to conceive the possible object of incurring extra expense in re-pumping liquor.

The Purifiers.—The gas passing from the scrubbers has now to be freed from carbonic acid and sulphuretted hydrogen, and sometimes a portion of the carbon disulphide present; and the function of the purifiers is to effect the removal of these substances. In the early days of gas purification lime alone was used to remove the carbonic acid and sulphuretted hydrogen, a quantity being mixed with water in the form of a liquid cream, through which the gas was made to bubble. A special contrivance called a wet lime purifier was used; this form of purification, however, is now almost obsolete, and the present description will therefore be confined to vessels in which the purifying material is used in the dry state. "Dry lime purifiers are generally rectangular iron vessels, varying from 3 feet to 30 feet square, and from 3 feet to 4 feet 6 inches deep. Sometimes in small works they are made circular; this, however, is not very frequent, and is done for convenience or economy of construction. Each purifier contains a series of perforated shelves, trays, or sieves, supported by suitable bearers of wrought or cast iron, the ends of which are attached to 'snuggs' cast on the purifier. In large purifiers there are also pillars placed at intermediate distances, to carry the weight of the sieves and purifying material.

"The upper part of the purifier is surrounded by a cistern or reservoir of from 6 inches to 24 inches deep, and from 3 to 6 inches wide, which is often cast with the purifier and forms part of it, or at other times is attached thereto by bolts and cement, and is for the purpose of containing water to seal the cover. The cover of the purifier is of boiler plate or cast iron. The rim or border of the cover is rather deeper than the cistern into which it is placed, and is effectually sealed by the water, so preventing the gas escaping from that point. Often the purifier is divided into two compartments, so that the gas ascends through a set of sieves on the one side, and descends through another set on the other side, answering the purpose of two vessels. In all establishments, however small they may be, two distinct purifiers at least are necessary, to enable the impure lime to be removed from the one whilst the gas is being purified by the other. The number of purifiers in a work is variable; in the majority of establishments a set of four is very usual, their dimensions being determined by the capacity of the works, the general calculation when dry lime is used being to allow one superficial yard of sieve for every 1000 feet of gas produced per diem. Thus, a works producing 50 millions per annum (or a maximum of 220,000 per day), will require four purifiers, each 9 feet square, having six sieves each."—Hughes.

The purifiers have generally a special building allotted to them, termed the purifying house. There is generally a mechanical contrivance for readily removing the purifier lids, and lifting them out of the way during the discharging and recharging the vessels. For this purpose hydraulic power is sometimes used in a special form of purifier, but the most general method is that of having a small lifting apparatus actuated by hand power, and which travels along rails arranged at a suitable distance above the purifiers. When the contents of a vessel require changing, the valve is shut off, and a valve on the lid opened; the levers which fix down the lid are then shifted, and the lifting apparatus moved along until it is immediately above the centre of the purifier. A chain with hook attached is then lowerd and affixed to a corresponding hook in the centre of the purifier lid, and the latter being then lifted off, is carried by the travelling lift out of the way, and deposited on the top of one of the other purifiers until required. When the purifier is sufficiently free from gas, men descend and shovel out the spent material, removing the grids as they descend; the grids used for supporting the purifying agent being replaced in succession during the recharging. The purifier lid is then replaced, and the gas turned on, being allowed to escape for a short time through the open valve in the lid, in order to expel the air with which the purifying vessel has become filled during the discharging and recharging. The precaution of expelling the air is necessary, in order to avoid the undue loss of illuminating power which the gas would otherwise suffer from its admixture with air.

It will now be necessary to describe the mode of working the purifiers. The exact method employed, as well as the actual number of vessels required, will vary with the conditions of purity which the gas company are required to fulfil. Local companies, for instance, which are under but limited restrictions, can use oxide of iron alone, having only to free the gas from sulphuretted hydrogen; and under these conditions a very limited number of purifiers will answer the purpose, the required system of valves being correspondingly simple. Figs. 8 and 9 show the ordinary construction of dry valves, such as are used for shutting off and turning on the gas.

Where, however, the company is bound to supply gas not only free from sulphuretted hydrogen, but likewise containing a limited amount of sulphur in other forms, the purification becomes more complicated, and the number of purifying vessels required correspondingly numerous; more especially as, in order to comply with the required conditions, provision must be made not only for removing sulphuretted hydrogen, but likewise carbonic acid, and part at least of the carbon disulphide. Firstly, then, with regard to works in which sulphuretted hydrogen is the only impurity which must of necessity be removed from the gas before being supplied to the consumer, sometimes lime and sometimes oxide of iron are used, and occasionally both; oxide of iron is, however, most convenient in use and cleanly in operation, and should always, where possible, replace lime for these reasons. It is now customary, on all moderate-sized works, to have at least a series of four purifiers, worked by a centre valve, three out of the four being continually in use, while the fourth is being recharged with fresh material. The construction of a dry centre valve, such as that known as "Walker's," will be understood from the following description, which we quote from Clegg:—

"The centre is made in three parts. The lower chamber, which is divided by partitions into separate compartments leading to the pipes forming the inlets and outlets of the purifiers, is accurately surfaced on its upper horizontal face. The upper part consists of a circular chamber, which has an inlet through which the foul gas is admitted. The valve inside this chamber, which is also divided into corresponding compartments, accurately surfaced on the lower horizontal face, covers and works

Fig. 8.

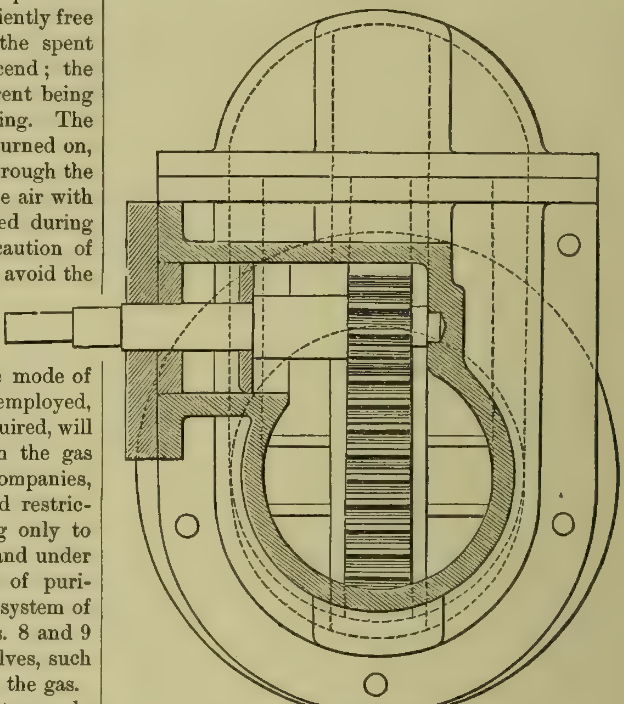
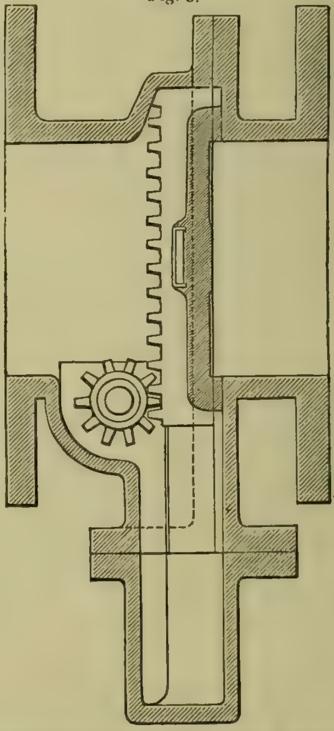


Fig. 9.



upon the lower chamber. It has one opening right through it, which constitutes its inlet, through which the gas flows down into the inlet of the first purifier. This upper circular chamber may be turned round by a spindle that passes through a stuffing box. After passing through that purifier the gas enters the next opening in the centre chamber, and by means of the divisions of the valves passes into the adjoining opening, which leads to the inlet of the next purifier, and after passing through that purifier returns to the centre chamber, to pass into the third purifier. The gas thus purified returns once more to the centre chamber; and if there are four purifiers in the series, into the outer one, which has an outlet pipe in the side leading to the gas-holder, thus leaving one purifier ready to be cleared. When the last purifier is foul the valve is moved partly round, so as to bring the inlet to the second purifier, which cuts off the gas from the third one; and it then passes through three of the purifiers, entering the fresh-charged purifier last.

"The outer case is properly surfaced and made easily removable, to permit access to the internal parts at any time. When arranged to work three purifiers the gas passes through two, leaving one shut off for recharging; when arranged for two purifiers it passes through one, the other being shut off; and whatever the number one purifier is always shut off to be cleaned and recharged." Messrs. WALKER state that these valves will keep perfectly sound if the precaution be taken of oiling and cleaning the working parts about once a year.

This description of valve here mentioned belongs to the class known as "dry valves," in contradistinction to those termed "hydraulic," in which perfectly fitting metallic surfaces are unnecessary, a gas-tight union being effected by a water seal. Both classes of valves have their respective merits and demerits; the dry valve is, however, most largely in use, not only in the form of centre valves for purifiers, but as single valves in use in all parts of a works. The greatest objection to the dry valve as a centre valve for purifiers, is that its efficient action depends entirely on the accuracy with which the metallic surfaces fit, any deficiency in this respect allowing a leakage of foul gas into the purified material. On the other hand, although the hydraulic or water valve is free from the last-named defect, it is open to objection on the score that the water used to effect the sealing is in contact alike with the purified and unpurified gas, so that the former frequently becomes slightly contaminated.

As the changing of lime purifiers is generally attended with the emission of a most objectionable smell, which may become a nuisance to the neighbourhood in which the gas works are situated, it becomes a matter of importance to conduct the purification in such a way as to avoid, as far as possible, the evolution of any unpleasant odour. Where the gas company are not under restrictions as to sulphur in any other form than sulphuretted hydrogen, it is possible by a special method of working to so conduct the purification that the contents of the lime purifiers are always removed in the form of a comparatively inodorous carbonate of lime, thus reducing any objectionable smell to a minimum. This mode of working is more essentially a chemical question, and will receive attention under that portion of the present article which refers to the Chemistry of Purification, to which we must also refer the reader for a description of the special method of working necessary for the removal of carbon disulphide.

The Station Meter.—Before the purified gas passes to the holder, the quantity is ascertained by passing it through a large measuring apparatus termed the station meter. This, by registering the make of gas, enables the gas producer to keep a kind of check on the men's work, and at the same time enables him to ascertain the amount of gas which the coal is yielding per ton. The difference between the registration of the station meter and the aggregate register of the consumers' meters gives the loss entailed in distribution, arising from leakage, repairing mains, and other causes. The principle of the station meter is identically the same as that of the consumers' meter, the difference between the two being more that of size; the description and explanation of the meter given under the head of consumers' meters (wet), will therefore apply equally well to the station meter.

The case of the station meter is constructed of cast iron, the inlet and outlet pipes being at the back. The height of the water line is indicated by a gauge. In front of the meter is the dial-plate, indicating the amount of gas passed, the maximum amount capable of being recorded being regulated by the size of the meter. An apparatus called "a tell-tale" is likewise attached to the dial-plate of the meter, and shows by its indications whether the production of gas has been regular for each hour out of the twenty-four. Of this apparatus the following accurate description is given by TOMLINSON:—

"In the centre of the *dial-field* is fixed a circular plate connected with a train of wheel-work, set in motion by an inclosed drum, through which the gas passes, indicating tens of thousands, hundreds of thousands, millions, and tens of millions of cubic feet of gas. Upon this plate is fixed a disc of paper, divided into 24 parts, with subdivisions. Suppose the meter to register 300,000 cubic feet in twenty-four hours, and the plate to be connected by wheels in the ratio of three to one to that index, which marks 100,000 in one revolution; it is evident that the distance travelled by one of the twenty-four divisions of the plate from a certain fixed point, will indicate the quantity of gas made in one hour, or $\frac{300,000}{24} = 12,500$ cubic feet. Above this divided disc is a timepiece, to the minute-hand of which is attached a detent, furnished with a pencil pressing by a spring upon the disc. As the minute-hand of the timepiece revolves, the pencil, by means of a guide fixed to the meter-case, is regulated, so that in the first half hour it will make a vertical line upon the paper, in length equal to the diameter of the circle formed by the minute-hand, measured from the centre to the point at which the detent is fixed; in the second half hour the line will be retraced by the hand rising again. This arrangement supposes the divided disc to be stationary; but as it is made to revolve on an axis, which is also the axis of the internal drum, set in motion by the gas, the pencil will make a series of curved lines, meeting the divided circle of the disc every hour, and the distance travelled from point to point will mark the number of cubic feet of gas made during every hour of the twenty-four. If the production of gas is regular the figures formed by the pencil will be so also; if, on the contrary, any neglect has occurred, the irregularity of the figure will detect it, and point out the hour and the amount of difference; because, if the speed of the revolving disc be decreased the figure formed will approach nearer to the straight line; if increased, the points of intersection upon the divided circle will be further apart." The case of the station meter is usually ornamented, and bears an appropriate inscription, together with the name of the company and date of erection.

The largest station meter yet erected has just been completed by Messrs Parkinson & Co., for the works of the Chartered Company at Bromley.

Gas Holders.—The figure given in Plate I. will illustrate the modern method of gas holder construction.

Gas holders are of two kinds, the single lift, which is the simplest form of construction, and which is that shown in the Plate, and the double lift or telescopic. The latter form of holder is only used where it is desired to effect great economy of space, the telescopic holder being capable, from its greater height, of storing a far larger quantity of gas in a given area than the ordinary holder. The following excellent description of the ordinary or single lift holder is taken from Hughes.

"The gas holder is composed of two distinct parts, one of which contains water, and is called the tank, the other is the vessel which contains the gas, being really the gas holder. On the Continent the former is very generally termed the "cistern," and the latter the "bell." The tank is a large cylindrical vessel, constructed usually, for the sake of economy, of brickwork or masonry; but when the ground is marshy, or when water exists abundantly a short distance below the surface of the earth, which would prevent the construction in masonry at a moderate price, then tanks are made of cast iron, and, indeed, in small works are often of wrought iron. In the interior of the tank there are two vertical pipes for the admission and egress of the gas, called the inlet and the outlet pipes; the former being in direct communication with the manufacturing apparatus, the latter with the mains which convey the gas to the town. These pipes rise a few inches above the level of the top of the tank, so that the water cannot overflow into them. A series of columns, generally of cast iron, but sometimes of wood, or brick piers, are placed at equal distances around the tank for the purpose of guiding the holder.

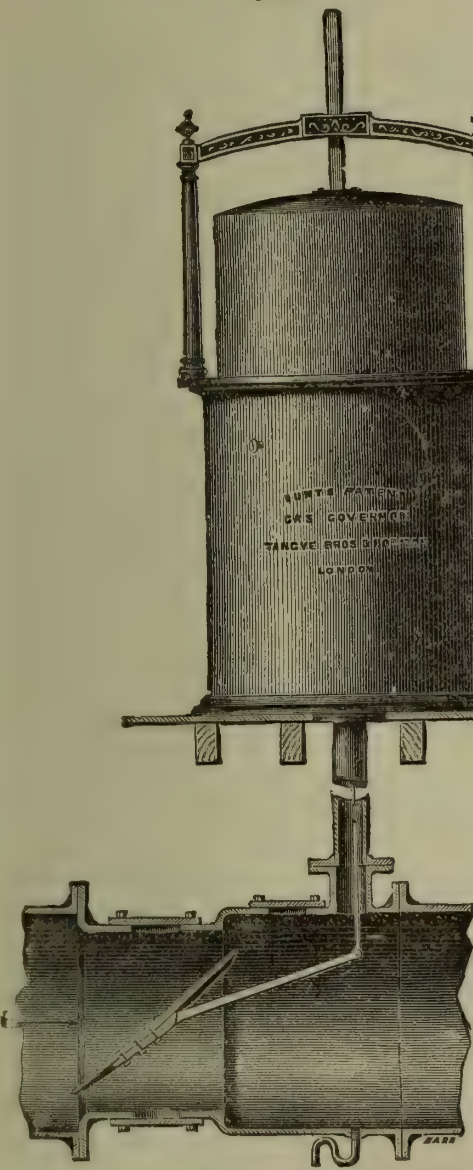
"The holder is a cylindrical vessel closed at the top, which is termed the roof, and open at the bottom, made of sheet iron, varying in thickness according to the dimensions of the apparatus; the smaller sizes being constructed of thin material, in order to avoid an excess of pressure, whilst those of very large dimensions are made of stout plates, for the purpose of obtaining sufficient pressure to expel the gas to the burners. The holder is somewhat less in diameter, but of the same depth as the tank in which it is placed, sometimes being partially suspended by chains which pass over grooved pulleys and counterbalance weights, but more frequently only guided by rollers attached around its lower and upper edges, which work against suitable guides in the tank and on the columns, in such a manner as to permit the holder to ascend and descend in the tank with the greatest freedom. . . . .

"The holder should be so constructed that when it is full, or at its greatest height, the lower edge will be so far under the water as to prevent the possibility of escape of gas. The water in the tank serves three purposes; it is the means of resistance of the gas to lift the holder; it prevents the gas escaping or intermixing with the atmosphere, and is the means of expelling the gas when the holder descends." In the majority of gas holders the roofs are strengthened by "trussing." This trussing (says Hughes), "consists of a series of radiating bars of T or flat bar iron, diverging at equal distances from the centre plate, called the 'crown plate,' to the angle iron or top curb, or angle of the holder. The roof is sustained by a kingpost in the centre, which is supported by tension rods from the top curb; there are also suspension rods which carry struts for sustaining the centre of radiating bars. A series of circles of rafters attached to the radiating bars complete the trussing of the roof. The sides in large holders have also trussing to prevent the holder 'bulging' or 'buckling' when on the ground." Gas engineers are by no means unanimous in their opinion as to the necessity for trussing holders, some advocating the use of untrussed holders; and one of the latter, of large size, has recently been successfully erected at the works of the South Metropolitan Gas Company, and is now in use. If a system of trussing could with safety be dispensed with, a considerable saving in expense of construction would be effected; it is, however, doubtful whether it would be safe to erect untrussed holders in any but sheltered situations.

As the gas holder throws a pressure which, as a rule, greatly exceeds that necessary for the proper circulation of the gas in the mains, it is customary to reduce the pressure at the outlet of the holder by means of an apparatus termed a governor, and which is to a great extent self-acting in its nature. The ordinary form of governor is shown in Plate I. It consists essentially of a small holder partly immersed in water, and which can be weighted to any required amount by weights placed on the top.

The gas is controlled by means of a conical valve, through which the gas enters the holder, the quantity allowed to pass depending on the space between the valve cone and its seat. The cone of the valve is suspended by a chain from the top of the holder, so that when the holder rises by any increase in the initial gas pressure, it carries with it the valve cone and partially closes the valve, thereby reducing the excessive quantity of gas that would otherwise have passed to the main. With a fall in the initial gas pressure, the holder descends and allows the valve cone to fall more or less from its seat, enlarges the gas passage, and permits an increased amount of gas to flow. The pressure may be adjusted to any required amount.

Fig. 10.



The governor tank is made of cast iron plates of a circular form, usually somewhat less in depth than the diameter, and with the capacity of about 2 cubic feet for every 10,000 feet of gas required to be passed through in twenty-four hours. The lifting part or holder is about the same depth, and about 4 inches less in diameter. The valve cone is made of solid iron turned true in a lathe, and varies from about 6 to 15 inches in diameter at base, with about 2 at top. The orifice at the top of the inlet pipe is also bored true and of a conical form, so as to fit the base of the cone.—Hughes.

Another form of governor is that known as Hunt's equilibrium governor, the action of which will be best understood by reference to the illustration, Fig. 10. In this form of governor, the regulating action is originally obtained by a holder partly immersed in water; but instead of a conical valve, the regulation is effected by a throttle valve situated in the main.

In places where the district supplied varies in level, it is often necessary to place governors at various points, in order to check the increase of pressure which would otherwise take place at parts elevated some distance above the works. The increase of pressure which occurs from a rise in elevation is usually reckoned as a tenth of an inch of water for every 10 feet; while, on the other hand, where the gas has to travel to a *lower* level, a *loss* in initial pressure takes place in the proportion of a tenth less pressure for every descent of 10 feet.

Purification of Gas.—It is proposed, in this part of the present article, to consider the various means now in use for the elimination of the different impurities found in the crude gas as it leaves the retort, as well as to explain the nature of the chemical changes which take place during purification.

The substances present in the crude gas which are regarded as impurities, and which are wholly or partially removed before the gas is considered sufficiently pure for supply to the consumer, may be enumerated as follows:—

Carbonic acid,
Ammonia,
Sulphuretted hydrogen,
Sulphurous acid, (?)
Bisulphide of carbon,
Cyanogen compounds,
Suspended tarry and aqueous vapours.

Before going further, it may be well to explain the reason for its being considered necessary to remove the above-named substances from the gas prior to its being supplied to the public.

Carbonic acid is chiefly objectionable on account of its exercising a lowering action on the illuminating power, 1 per cent. of this substance (according to Clegg) effecting a reduction of 6 per cent. on the lighting power. The presence of *ammonia* causes the gas to act with more or less rapidity on any brass or copper fittings with which it may come in contact; and as the removal of this substance from the gas can be accomplished without difficulty, and is a source of considerable profit to the companies, there is no excuse for the presence of ammonia in quantity in the purified gas. *Sulphuretted* *hydrogen* is one of the most obnoxious impurities of crude gas, and if not removed before the gas is supplied to the consumer, acts deleteriously by causing all bright metal work, such as silver plate or picture frames, to rapidly tarnish, if by any chance there should be a leakage of the impure gas. *Sulphurous acid* is an impurity which, though objectionable, is not likely to be present in the gas as supplied to the public. With regard to the bisulphide of carbon, the *actual* amount of this substance present in ordinary gas is exceedingly small; but there is a strong public feeling against the so-called "sulphur compounds," and there has been lately much agitation on the subject. When gas containing this impurity is burned *sulphurous acid* is formed, which, however, does not remain as such for any length of time, but is rapidly changed by oxidation into the more noxious form of *sulphuric acid*, which deposits together with the condensed moisture to a greater or less extent on the various articles about the room in which the gas is being consumed, and exerts a corrosive action on them. Leather articles, such as the binding of books, are the most seriously affected; but the action is extremely slow, and there is every reason to believe that no serious damage is to be apprehended from gas which is moderately pure. The remaining substances, viz., "cyanogen compounds" and "tarry and aqueous vapours," become separated from the gas naturally during the ordinary purifying processes, and do not in any way affect the consumer.

The first stage of the purifying process begins when the crude gas leaves the retort and travels along the hydraulic main, a partial deposition of the tarry and aqueous vapours taking place together with a small portion of the ammonia compounds; very little real purification is, however, here effected, as the gas is still in a heated condition; and it is not until its passage through the condenser, where it becomes reduced to a normal temperature, that purification proper can be said to commence. The gas generally enters the condenser at a temperature of about 130° Fahr.; but much naturally depends on the heat at which the retorts are being worked. Passing through the condenser, nearly the whole of the tarry vapours previously held in suspension become deposited, collecting as liquid tar, while at the same time a quantity of weak ammoniacal liquor is formed by the condensation of the aqueous vapour present charged with ammonia. The quantity of liquor obtained here may be taken at about 9 gallons to the ton of coal, of about 6 or 7 oz. strength; and this quantity represents about one-fourth of the total ammonia present in the unpurified gas. A certain quantity of carbonic and sulphurous acids, cyanogen compounds, and sulphuretted hydrogen, are likewise separated from the gas at this point, in combination with the deposited ammonia. It is of the utmost importance that the condensing power should be properly proportioned to the "make" of gas, as if the temperature of the gas is not properly reduced before it enters the scrubbers, neither those vessels, nor yet the condenser itself, can be said to be performing their work efficiently, and, as will be subsequently shown, extra work is thrown upon the purifiers proper. It should also be remembered that any suspended tarry matter not deposited in the condenser is carried forward by the current of gas and arrested by the scrubbers, which become impeded in their action and finally choked.

The gas should leave the condenser at a temperature which should not, if possible, exceed 60° to 65°; and it may be here pointed out, that the cooler the gas enters the scrubbers the greater the degree of purification which they will effect. On some works it is customary to pass the gas through what is termed a "dry scrubber" previous to its entrance to the scrubbers proper. This is merely a vessel filled with twigs or dry coke, and is intended to arrest any tarry matter which may pass the condenser; but it is obvious that if the latter vessel is performing its work efficiently, anything supplementary, such as a dry scrubber, is quite superfluous. The function of the ordinary wet scrubber is the separation from the partially purified gas of the whole, or nearly the whole, of its remaining ammonia, together with a certain further amount of other gaseous impurities. A good scrubber should be capable of removing all but a trace of ammonia from the gas, using, at the same time, a minimum amount of fluid for the purpose. It should likewise present as large an amount of surface as possible to the entering gas, and the better this condition is fulfilled, the greater will be the efficiency of the scrubber. There are many descriptions of these vessels in use, but the two which are the most known and most frequently used are the Mann scrubber and the Livesey scrubber. The former removes the ammonia with greater completeness from the gas, but the latter has the merit of giving no back pressure, and of not being subject to stoppage of any description, working for apparently any length of time without change of material. The Mann scrubber being charged with coke is, it is stated, somewhat liable to become more or less choked with tarry matter, thus giving rise to back pressure; although there is every reason to believe that, where the condensers are working properly, there is but little to fear on this score; and Mr. Mann himself testifies, that with ordinarily careful working the coke only requires changing once every three years. The Livesey scrubber, having its internal construction of deal boards, is comparatively light, but it is very doubtful whether, for a given size, it can present such an extent of surface as if charged with coke. This opinion would appear to be supported by the fact, that the Mann scrubber is found in practice to be more effective in removing all but mere traces of ammonia from the gas, while it will, at the same time, produce a stronger liquor.

Whatever form of scrubber is used, the action, *pro rata*, is the same, and consists in the separation of ammonia, mainly in combination with carbonic acid and sulphuretted hydrogen, a small residual quantity, however, generally remaining in the free state. It is obvious that the greater the quantity of sulphuretted hydrogen and carbonic acid which can be removed from the gas in combination with ammonia by the action of the scrubber, the greater the saving in the amount of purifying material which has to be subsequently used; and a chemical examination of various gas liquors has shown, that in this respect the scrubber does not always act as efficiently as it might. Analysis of gas liquor will not unfrequently reveal the presence of a considerable quantity of ammonia in the free state; and as ammonia in this condition is as much a purifying agent as lime or oxide of iron in its capability of absorbing sulphuretted hydrogen and carbonic acid, it follows that any ammonia found in this state is simply so much purifying material wasted. The conditions necessary for insuring the maximum removal of carbonic acid and sulphuretted hydrogen by the scrubber are—firstly, that the gas shall enter the vessel at the lowest possible temperature; secondly, that as much internal surface as possible shall be presented; and thirdly, that the gas shall not pass through too rapidly, as it must be borne in mind that a chemical action is taking place, and in all such cases time must be allowed for the necessary changes to occur. With regard to the amount and strength of liquor obtained from one efficient scrubber in good working order, both will of course vary with the character of the coal and the quantity of water used per ton; the average amount may, however, be taken at from 10 to 12 gallons of 14 oz. liquor, the total yield from the coal, that is the scrubber and condenser liquor together, being generally taken at from 20 to 25 gallons of 10 oz. liquor.

With regard to the exact composition of gas liquor, there is but little published information on the subject, but the general constituents are combinations of ammonia with carbonic, hydrosulphuric, sulphurous, sulphuric, cyanic, sulphocyanic, and hyposulphurous acids, together with a small quantity of ammonia in the free state, the relative proportions of each compound being subject to considerable variation, and depending much on circumstances. It is the policy of the gas manager, as far as it lies in his power, to prevent the formation of the comparatively fixed compounds of ammonia, that is, of any combinations other than the sulphide and carbonate; as when the alkali is, as it were, thus bound up, it not only entirely loses its efficacy as a purifying agent for the removal of sulphuretted hydrogen and carbonic acid, but its money value is (by the present method of valuation) considerably decreased. Under certain conditions, at present but little understood, it is found that the action of the coke scrubber becomes abnormal, and the oxidation and fixation of ammonia in the liquor which is produced becomes considerable, from the production of sulphuric and hyposulphurous acids in excessive quantity. This state of things is generally found to occur in the case of a *fresh* scrubber being started; and in an article on the "Chemistry of the Scrubber" in the *Gas Journal* for January 12, 1874, the writer there makes some speculations as to the cause of this excessive fixation of ammonia in the following quotation:—"Many conjectures have been made to account for the excessive production of these sulphur acids, but the question is still in an extremely unsatisfactory condition, for, although it is quite possible that when a scrubber charged with fresh coke is first started, sufficient oxygen is present in the pores of the coke to cause an oxidation of the sulphuretted hydrogen and sulphide of ammonium present, yet the production of the sulphur acids, and consequent fixation of ammonia, continues for a period considerably longer than would probably be the case if there were not some other less understood cause at work. Coke charged with atmospheric oxygen would act in a similar way to charcoal in promoting oxidation, but to a less degree. The action would be the formation of sulphuric acid and water from the direct oxidation of the sulphuretted hydrogen and sulphide of ammonium in the crude gas, but the liquor from scrubbers acting in this abnormal way contains a large quantity of hyposulphite of ammonia, and the presence of this substance is by no means so easily accounted for. The most probable explanation of its formation is founded on the reaction of sulphurous acid and an alkaline sulphide. Sulphide of ammonium is a normal constituent of crude gas, which likewise contains a small quantity of sulphurous acid, but not in anything like sufficient quantity to account for such a large quantity of hyposulphite. If, however, we admit that under certain conditions sulphuretted hydrogen or sulphide of ammonium could suffer a limited oxidation on meeting with the condensed oxygen in the pores of the coke contained in the scrubber, and give rise to *sulphurous* acid instead of *sulphuric*, the formation of hyposulphite would be more intelligible. We should have the equation—

$$2NH_4S + 3SO_2 = 2NH_4,S_2O_3 + S,$$

in which the sulphide of ammonium and sulphurous acid mutually react on one another with corresponding formation of hyposulphite. That this view of the case is a correct one can hardly be advanced, it has only perhaps the merit of probability."

The writer at the same time remarks, that sulphurous acid would also find its way into the gas in large quantity if there was any excess of exhaustion going on, and more especially if the retorts were to any degree leaky, through cracks or imperfections. The admission of sulphurous acid by this means would doubtless cause the formation of sulphate and hydrosulphate of ammonia, and the consequent fixation of that substance in abnormal quantity.

Besides scrubbing as a means of removing ammonia from crude gas, there are other methods in use, either by preference or from motives of convenience. Foremost among these is the use of washers, the action of which vessels in the purification of gas is exactly similar to that of scrubbers, the only difference being that without some supplementary means it is difficult, if not impossible, to remove the whole of the ammonia from the gas by simple washing. The latest and most improved form of washer, as recommended by Mr. GEORGE ANDERSON, appears, however, to yield excellent results, and to be attended with many advantages over the use of scrubbers. The main objection, however, to the use of washers, appears to be that the conditions of giving as much surface, and as intimate contact of the gas with the liquid used for purification, are not so perfectly fulfilled as in the scrubber; for in the latter vessel the gas is certainly brought into the most intimate possible contact with the liquid by means of the wet coke, while in the case of a washer the gas passes through in actual bubbles, the outsides of which are the only portions subjected to the action of the liquid, and the subsequent effect cannot possibly be so perfect. In addition to the washer, in which the purifying liquid is either ordinary water or weak liquor, there is the washer sometimes used in small works, in which the liquid is dilute sulphuric acid. Provided the gas be judiciously distributed, there is no doubt that the removal of ammonia by this means is very complete; but where sulphuric acid is used for this purpose, it will be found to be more convenient to mix it with sawdust as an absorbent, and use the compound in a special purifier in the ordinary way. There is, however, one great objection to the use of sulphuric acid for the elimination of the ammonia from gas, and that is, that the beneficial effect of the ammonia itself, as a purifying agent for the removal of sulphuretted hydrogen and carbonic acid, is entirely lost, by the immediate conversion of the ammonia into sulphate. Not only is this true of the ammonia in the free state, but the ammonium sulphide and carbonate existing in the vaporous or suspended form in the crude gas become entirely decomposed, their ammonia being retained by the sulphuric acid, while an additional amount of carbonic acid and sulphuretted hydrogen is thus thrown into the gas, to be subsequently removed by a greater expenditure of lime and oxide in the purifiers.

There is yet one other substance used for the elimination of ammonia from gas, and that is the sulphate of iron. This material is used in an ordinary purifier, and removes not only ammonia, but likewise sulphuretted hydrogen; the sulphuric acid of the ferrous sulphate uniting with the ammonia of the gas to form ammonium sulphate, while at the same time the ferrous oxide becomes liberated, and in its turn absorbs sulphuretted hydrogen, with which it unites to form ferrous sulphide.

Having dealt with the removal of ammonia from the crude gas, and the various means employed for that purpose, we have now to pay attention to the methods used for the elimination of the remaining impurities from the partially purified product, and likewise to discuss the chemical changes which take place.

The substances to be dealt with at this stage of the purifying process are the residual sulphuretted hydrogen and carbonic acid not eliminated in the scrubbers or washers, and the sulphur existing as bisulphide of carbon. In country works, where the companies are not liable to any penalty for the presence in undue quantity of sulphur compounds other than sulphuretted hydrogen, the separation of the bisulphide is of course of no consequence; but in such works as those of the London companies, where the presence of an excess of these sulphur compounds above a prescribed amount is considered penal, the removal of bisulphide of carbon is of the utmost importance, and this branch of the subject will therefore receive considerable attention.

Leaving the scrubbers, the gas enters the purifiers containing either lime, oxide of iron, or both these substances. Oxide of iron absorbs only sulphuretted hydrogen, while lime deals not only with that compound, but likewise with carbonic acid.

With regard to the general use of lime and oxide as purifying agents, there is much difference of opinion as to the comparative merits of each, but the usual plan now is to use a certain portion of both, assigning to each its own special work. Local circumstances and position of works will perhaps affect the question more than any other consideration, for on these points will depend the facilities for procuring purifying material, and likewise the cost of obtaining it. In districts where lime is cheap, and the works so situated that the removal of the refuse lime can be effected without causing a nuisance, lime would doubtless be the most suitable purifying agent; where, however, there are facilities for procuring the oxide of iron without any considerable cost for transit, it is preferable to substitute this substance as much as possible for lime, as entailing less trouble and being cheaper in the first instance, while it likewise has the great advantage of causing considerably less back pressure than lime. The fact of the thoroughly spent oxide being sufficiently valuable (by reason of the free sulphur which it contains) to be carted from the works free of charge by those who originally supply it, is a consideration of no mean value when the difficulty frequently experienced of getting rid of refuse lime is considered. It is probably the best plan in practice to use both lime and oxide, placing the former first, and then by systematic working the lime may be always removed as inodorous carbonate, thus avoiding all nuisance. Where, however, the sulphur compounds other than sulphuretted hydrogen have to be kept under a specified amount, as in the case of many of the London works under special Acts of Parliament, the work of purification is attended with considerably more difficulty, and the only means of obtaining the desired result is by the use of lime in a special way, which will be described when we come to treat more especially of lime purification. There has been much discussion lately on the best mode of arranging the purifying material, some holding that the whole bulk necessary for charging a purifier should be placed in a single layer, whilst others, who are in the majority, advocate a distribution of the material into two, three, or even four tiers; and it seems to be generally acknowledged, as a universal practice, that the most advantageous method of charging the purifiers is by the use of three separate tiers of material of moderate depth. When a comparatively deep mass of material is used, as when the purifying medium is placed in a single layer, the under portion becomes unduly compressed, giving rise to an undesirable amount of back pressure, and the gas then forces its way upwards as best it can, and creates channels for itself through limited portions of the purifying material, the greater part of which remains for some time comparatively unchanged. A mass of lime or oxide, having the depth which it would necessarily possess when a full charge is arranged in a single layer, has a tendency to sink most towards the centre of the mass, which falls away in consequence from the sides of the purifier, and allows the gas to pass with undue freedom along the channels thus formed; when, however, the purifying material is arranged in tiers having comparatively little depth, less subsidence takes place, and the gas is able to equalize itself between each layer before passing through the next in succession, so that the maximum effect is obtained. With regard to the amount of purifying material necessary per ton of coal, a great deal will depend on the quality of coal used, and still more perhaps on the particular way of working; it is, however, generally assumed that a bushel of lime will, when slaked, by which its bulk is doubled, purify the gas from a ton of coal (Clegg says 10,000 feet of gas), while a bushel of oxide will suffice for the gas from 5 tons of coal. In giving this general estimate it is assumed that the respective purifying materials are of good quality, and are being used in the most advantageous manner, but there are many considerations which would considerably modify the figures given. If the scrubbers and washers are of the most approved form, and acting with efficiency, a considerable amount of sulphuretted hydrogen and carbonic acid will be removed at that stage of the purifying process. If lime and oxide are both being used, a larger amount of gas can be efficiently purified by using the lime first. Much will likewise depend on the arrangement of the purifying material in the purifiers; and it may here be remarked that, whichever substance is being used, it should be handled as tenderly as possible, as too much care cannot be exercised in this respect. When a purifier is being charged the material should be handed down in baskets, and then distributed on the tiers with shovels as loosely as possible, as by this means it becomes, when subsequently used, more evenly fouled, and will be found altogether more efficacious.

Enough has now been said on the *general* principles of purification, and attention will be more particularly directed to special modes of working, and to the chemical changes which occur where lime and oxide of iron are used as purifying agents. The oxide of iron used in gas works is principally a natural product occurring in many localities, and is a hydrated sesquioxide of iron, having the composition $Fe_2O_33H_2O$. It is generally mixed with about two-thirds of sawdust previous to use, and on coming into contact with the foul gas containing sulphuretted hydrogen, a reaction takes places, which may be represented by the following equation:—

$$Fe_2C_33H_2O + 3H_2S = 2FeS + 6H_2O + S.$$

In which sulphide of iron is formed, while water is separated, which being absorbed by the sawdust, makes the whole mass more compact, and gives rise to the increased back pressure which is generally observed to occur as the material gets "fouled."

When the oxide is completely converted into sulphide, and is therefore for the time being useless as a purifying agent, it is removed from the purifier and exposed to the action of the air, by which treatment it becomes, after a short time, again fit for use as an agent for absorbing sulphuretted hydrogen. It is this capability of being revivified that renders oxide of iron so invaluable for purifying purposes, and gives it such a pre-eminence over every other material. The action which takes place when the "fouled oxide" is exposed to air will be best understood from the following equation:—

$$2FeS + 3H_2O + 3O \text{ (from the air)} = Fe_2O_3.3H_2O + 2S.$$

In which it is seen that under the influence of atmospheric oxygen, and in presence of water, hydrated sesquioxide of iron (the original substance) is reformed, while sulphur is separated in the free state. The fouled oxide requires care and attention during this treatment, and should be watched and stirred about occasionally, as by reason of the chemical action which is taking place a considerable amount of heat is developed, and unless this is prevented from becoming excessive, the particles of material are apt to become aggregated together into "lumps" from the partial fusion of the free sulphur present. This aggregation has the effect not only of causing the oxide to assume a condition *physically* less suited for purification, but it likewise actually diminishes its purifying power, inasmuch as the semi-fusion of the sulphur binds together the particles of oxide, and by exerting a protective action, renders them unable ultimately to absorb the sulphuretted hydrogen.

When the oxide has become completely revivified it is again fit for use in the purifiers, and when "fouled" may be again revivified, repeating the processes of "fouling" by absorption of sulphuretted hydrogen and "revivification" by exposure to air, until it becomes so charged with free sulphur that it is expedient to substitute fresh material; and this stage is generally reached when it is found that about 40 per cent. of free sulphur is present, although a larger quantity is not unfrequently found.

The chemical changes which occur when lime is used as a purifying agent will now receive attention. Oxide of iron is only competent to deal with sulphuretted hydrogen; while lime is not only capable of removing this substance, but likewise carbonic acid. Lime can also be made to remove the bisulphide of carbon when used in a special way, and its action on this substance will be explained at some length when the comparatively simple reactions which occur when it is merely used for removing carbonic acid and sulphuretted hydrogen have been disposed of.

In order to render the caustic lime suitable for purification, it is first converted into hydrate by "slaking" with water, by which its bulk becomes considerably increased. The action which takes place is the union of a single equivalent of lime, or oxide of calcium, with one of water, thus—

$$CaO + H_2O = CaH_2O_2.$$

When this hydrate of lime is placed in the purifier, and there meets with sulphuretted hydrogen and carbonic acid, sulphide of calcium and carbonate of lime are formed. The two reactions take place simultaneously; but it will be best, for the sake of simplicity, to represent them separately, taking the action with carbonic acid first.

$$CaH_2O_2 + CO_2 = CaCO_3 + H_2O.$$

The formation of sulphide of calcium, consequent upon the union of the lime with sulphuretted hydrogen, may be represented by the equation—

$$CaH_2O_2 + H_2S = CaS + 2H_2O.$$

The action which takes place when carbonic acid and sulphuretted hydrogen are removed from crude gas by means of lime will thus be understood, and this degree of purification for many works, and more especially for those situated in the country, is generally deemed sufficient, no special application of lime for removing bisulphide of carbon being needed.

In the general remarks on purification it was stated, that where lime and oxide are both used, it was found that the lime was most efficacious when placed first. It would seem at first sight that the better plan would be to place the oxide first, which would absorb all sulphuretted hydrogen, leaving the lime to subsequently remove the carbonic acid; but not only has this method not been found the most efficacious in practice, but there is a strong reason for the converse arrangement being the best. When carbonic acid acts directly on the hydrate of lime, as has been already explained, carbonate of lime is formed and water separated; but the action as it takes place in a purifier is never complete when the carbonate is formed in this way. The lime used is frequently a little lumpy, and as the action of absorbing carbonic acid progresses there is a tendency in the particles of the material to become aggregated; the masses thus formed, as well as the nodules of lime originally present, become covered with a superficial crust of carbonate, which in a great measure protects the inside portions from further action. It is thus eventually found, when the material is removed from the purifier, after being apparently spent, that it still contains a very appreciable quantity of lime uncarbonated and in the free state. There is, however, another method of using lime for the removal of carbonic acid, in which the lime is first converted into sulphide, and subsequently into carbonate, and it is found in practice that the action of the lime is far more complete when used in this way. The action which takes place when carbonic acid meets with sulphide of calcium may be represented as follows:—

$$CaS + CO_2 + H_2O = CaCO_3 + H_2S,$$

carbonate of lime being formed and sulphuretted hydrogen expelled.

The fact of the production of carbonate of lime being more complete when a sulphide is intermediately formed than when the carbonate is produced by the action of carbonic acid on lime direct, is most probably to be explained by a physical cause. Referring back to the equations given, it will be seen that when carbonate of lime is formed by the action of carbonic acid on the hydrate of lime, water is separated, which causes a tendency to aggregation of the particles of lime. When, however, the carbonate is produced by the action of carbonic acid on sulphide of calcium, exactly the converse takes place, for water is taken up, and any nodules which may happen to be present become drier and more pervious to the gas, a condition favouring complete chemical action.

From the above considerations, it is unquestionably the best plan in practice to place the lime first, using the oxide afterwards. The first action is then the absorption of both sulphuretted hydrogen and carbonic acid by lime; a stage is then reached at which the lime is fully charged with impurities, and sulphuretted hydrogen begins to pass to the oxide. The lime, however, by reason of the sulphide of calcium which it contains, will still continue to absorb carbonic acid, forming carbonate of lime, and driving the sulphuretted hydrogen forward to be taken up by the oxide. When carbonic acid gas is found at the outlet of the lime purifier (known by testing with a little lime-water), it should be thrown out of action and a fresh one substituted. The contents will be found to consist of almost inodorous carbonate of lime, which can be removed without the least nuisance.

Having now traced the changes which occur during the removal of the ammonia, the sulphuretted hydrogen, and the carbonic acid from the crude gas, it only now remains to describe the means usually adopted for the elimination of the bisulphide of carbon.

The method generally adopted for the removal of this form of impurity consists in the use of lime purifiers worked in a special way. It has been long known in chemistry that bisulphide of carbon forms definite compounds, termed sulphocarbonates, with the alkaline sulphides, but it was a long time before this knowledge was turned to account in the purification of coal gas. The mode of working now in use for the elimination of the bisulphide is dependent, firstly, on the formation of sulphide of calcium in the purifier by the action of the foul gas, and secondly, on the formation of a sulphocarbonate of lime by the union of the sulphide of calcium with bisulphide of carbon. The production of sulphide of calcium has already been explained, and when this substance meets with bisulphide of carbon the following action takes place—

$$CaS + CS_2 = CaS.CS_2.$$

In which single equivalents of bisulphide of carbon and sulphide of calcium unite together to form an equivalent of the sulphocarbonate of calcium.

This reaction is taken advantage of in practice in the following way:—

A series of four purifiers are arranged, in which the first three vessels are charged with lime, and the last one with oxide of iron. On the admission of the foul gas, the first action which takes place is that the contents of No. 1 in the series become converted into carbonate and sulphide of calcium. The next action which then occurs is the decomposition of the sulphide of calcium by the carbonic acid present in the foul gas, carbonate of lime being formed and sulphuretted hydrogen expelled. This sulphuretted hydrogen, together with that present in the original gas, and which is passing unabsorbed by No. 1, pass together into purifier No. 2, whose contents become consequently converted entirely into sulphide of calcium, and are thus in a suitable condition for taking up the bisulphide of carbon. When the contents of No. 1 have in course of time become completely converted into carbonate, the carbonic acid in the entering gas begins to act on the sulphide of calcium in No. 2 vessel, converting it into carbonate of lime, and driving forward the sulphuretted hydrogen to No. 3 in the series; the contents of which become in their turn changed into sulphide of calcium, while any sulphuretted hydrogen passing unabsorbed is dealt with by the oxide of iron in the last purifier. No. 1 should now be charged with fresh material, so that by the time the contents of No. 2 have become completely carbonated the first vessel may be again ready for use; the order of the gas then being, through No. 3 to No. 1, and finally through the oxide in No. 4.

By this method of working it will be seen that all the impurities in the foul gas as it leaves the scrubbers are removed, while the spent material is a comparatively inodorous carbonate of lime, and this system is recommended by PATTERSON in his pamphlet on "Gas Purification."

There is, however, one consideration which neither that gentleman nor others writing on the subject seem to have noticed, but which is nevertheless of the utmost importance. It seems to be universally acknowledged by gas managers that when carbonic acid enters a sulphide purifier which has been used in removing bisulphide of carbon, and which consequently contains a certain proportion of the sulphocarbonate of calcium, that not only is the sulphide of calcium decomposed with expulsion of sulphuretted hydrogen, but that the sulphocarbonate itself is likewise acted on with formation of carbonate of lime and liberation of sulphuretted hydrogen and bisulphide of carbon. This bisulphide is for a time taken up by the sulphide of calcium always kept in advance, but a time must at length arrive at which the sulphide becomes surcharged with the bisulphide of carbon which is being driven out of the preceding lime-purifier by the action of carbonic acid, and it is then unable to deal with that portion of the bisulphide continually entering with the crude gas, and is therefore, for purifying purposes, quite useless. The only remedy is then to throw out the special sulphide purifier, the contents of which are so surcharged with bisulphide of carbon, and to substitute fresh sulphide of calcium in its place. The best plan in practice is, unquestionably, to keep a special sulphide purifier for the elimination of bisulphide of carbon alone, freeing the gas from *all other impurities* before attempting to remove the bisulphide, and allowing the gas to finally traverse a small catch purifier of oxide of iron, to arrest the small quantity of sulphuretted hydrogen which may be mechanically carried forward.

Other Methods for the Purification of Coal Gas, not Necessitating the Use of Lime or Oxide of Iron.—There have been many attempts made from time to time to partially or totally remove the impurities from crude coal gas without the expenditure of lime or oxide necessary under the system now in use, but up to the present time they have only met with partial success. It seems almost natural that in these numerous attempts gas liquor should have appeared to be the most suitable medium for experiment. Being a product obtained during the manufacture of the gas, and its supply being thus comparatively unlimited, containing as it does an alkali, ammonia, which in its free condition is as capable of absorbing carbonic acid and sulphuretted hydrogen as lime itself, gas liquor would appear to present unusual advantages to the inventor. As it is obtained, however, gas liquor is generally more or less saturated with gaseous impurities; and the problem of its successful utilization for purifying purposes resolves itself therefore into some means by which the impurities could be removed from the liquor, leaving the ammonia in a suitable condition to absorb fresh quantities of carbonic acid and sulphuretted hydrogen, accomplishing this, moreover, by some means which is attended with but little expense.

In the year 1866 LEIGH, of Manchester, patented a scheme for dealing with gas liquor; and his method was attended with sufficient success to warrant its partial adoption at the Manchester Gas Works, where it was specially applied to the removal from the gas of the sulphur compounds other than sulphuretted hydrogen. It was found quite possible to keep the amount of "sulphur" down to some 8 or 9 grains per 100 feet by the use of this process. In LEIGH'S patent he claims the treatment of crude gas liquor with caustic lime, by which the carbonic acid which it contains is removed by the lime, while an equivalent quantity of ammonia is liberated in the free state, the liquor being thus rendered again suitable for purification. Another method claimed consists in passing the liquor through a layer of foul lime, whereby the ammonium carbonate becomes changed to ammonium sulphide in the following way:—

$$(NH_4)HCO_3 + CaS = CaCO_3 + (NH_4)HS.$$

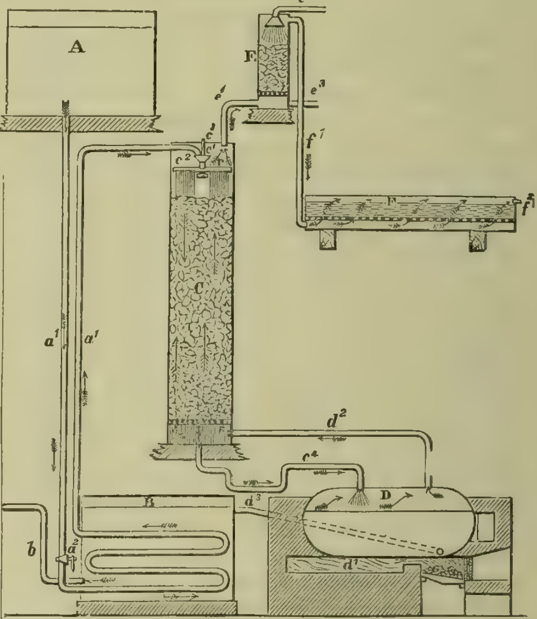
The liquor then contains only ammonium sulphide, and is specially suited for removing carbon disulphide. Another plan of LEIGH'S is that of concentration by distillation. The gas liquor being heated in suitable boilers, the ammonium sulphide and carbonate which it contains are evolved in a vaporous condition, and are, while still in that condition, passed through a layer of foul lime, and finally condensed. During the passage of the vapours through the foul lime, the ammonium carbonate becomes changed to ammonium sulphide, so that the final product is a concentrated solution of ammonium sulphide, which can be then used for removing carbon disulphide. In place of using the condensed tliquor, LEIGH sometimes prefers to conduct the vapours evolved from the heated liquor at once to the condenser, where they are allowed to act on the crude gas.

The treatment of gas liquor, so as to render it again suitable for purification, has, however, been more recently accomplished by HILLS; and his method appears to have already met with a certain degree of success, as well as to promise further and still better results in course of time. While LEIGH appears principally to aim at the economical production of ammonium sulphide for the special purpose of removing carbon disulphide, HILLS' process effects an entire purification of the liquor, so that it becomes capable of dealing with the impurities of crude gas as completely and effectually as if lime were being used.

HILLS' method is founded on the somewhat curious fact, that if a solution containing ammonium carbonate and sulphide be heated to a temperature of about 180° to 200° Fahr., the chemical affinity which exists between the ammonia and the gases with which it is combined is completely overcome. The carbonic acid and sulphuretted hydrogen thus pass off in the free state, while the ammonia previously in combination becomes set free and remains behind in solution; so that the purified liquor, after being cooled down to a normal temperature, can be again used for absorbing fresh quantities of carbonic acid and sulphuretted hydrogen from the crude gas.

The process is in practice carried on continuously, and the method of working will be better understood by reference to Fig. 11.

Fig. 11.



A is the reservoir containing the gas liquor to be purified; the liquor passes through a pipe, a^1, having a stop-cock, a^2, to a scrubber, C; the pipe, a^1, has several convolutions at its lowermost extremity, which are surrounded by the hot purified liquor passing from the boiler, D, through the heater, B. The crude gas liquor, after becoming heated by its passage through B, passes to the scrubber, C, which is charged with coke or other suitable material; and in order to insure a uniform distribution of the liquor, it flows by the funnel, c^1, into the pipe, c^2, where it flows out through small apertures. The pipe, with its attached funnel, is attached to a spindle, c^3, and the apparatus revolves after the principle of a "barker's mill." After traversing the scrubber, C, the liquor flows by the pipe, c^4, into the boiler, D, the contents of which are kept at as near as possible 180° Fahr. by means of the furnace, d^1. At this temperature the sulphuretted hydrogen and carbonic acid which the liquor contained, as well as a small portion of the ammonia, are liberated, and pass by the pipe, d^2, through the scrubber, C, where, meeting with the crude heated liquor, part of the ammonia is re-absorbed and carried back to the still or boiler, D. The sulphuretted hydrogen and carbonic acid pass on through the material in C and by the pipe, e^1, to the small scrubber, E, where any traces of ammonia still retained by the gases is absorbed by a flow of warm water or dilute sulphuric acid from the pipe, e^2. The liquor obtained here flows off by the pipe, e^3. The gases finally leave the scrubber, E, by the pipe, f^1; and the sulphuretted hydrogen being absorbed by a layer of oxide in the vessel, F, the residual carbonic acid is conducted to the furnace chimney by the pipe, f^2, and is thus got rid of. The purified liquor passes away from the boiler, D, by the pipe, d^3, into the heater, B, and from thence by b to a suitable vessel, where it is stored for use.

LIVESAY has found from practical experience of HILLS' process, that he is enabled to effect a saving of one half the amount of lime previously used. He is, however, using the system in a special way, making use of the purified liquor only for the removal of carbonic acid from the crude gas, thus leaving the sulphuretted hydrogen to be subsequently absorbed by lime. The calcium sulphide so formed is then used for the elimination of carbon disulphide. In a recent paper read by LIVESAY before the British Association of Gas Managers, he expressed a hope that he would be eventually able to considerably extend HILLS' process, and that it would in time be found capable of dealing with the whole of the removable impurities of crude gas, by which means a much greater saving would be obtained than is at present possible. This desirable end LIVESAY hopes to accomplish by using the purified liquor to a sufficient extent to remove all the sulphuretted hydrogen and carbonic acid from the crude gas, thus altogether dispensing with the use of lime or oxide of iron; while a specially prepared solution of ammonium sulphide, which could be obtained by HILLS' process without difficulty, would deal with the "bisulphide impurity." It would certainly be an immense advance in gas purification if this could be accomplished, and if all the necessary steps in the process can be conducted with the requisite economy, there appears to be every reason to suppose that the new process would be an established success. The purification being conducted throughout in closed vessels, thus avoiding the nuisance arising from the exposure of fouled materials to the atmosphere, is also a consideration of no mean value, and one which in itself should be a powerful inducement for the adoption of the new system.

An attempt has recently been made by VERNON HARCOURT to remove the carbon disulphide from gas by the action of heat, in a somewhat similar way to that tried many years ago by BOWDITCH. The latter gentleman found that when gas containing the vapour of carbon disulphide was passed over heated lime, that a decomposition took place in which the disulphide was broken up with formation of an equivalent quantity of sulphuretted hydrogen. The scheme, however, was not permanently adopted owing to the expense and difficulty then attendant on heating gas in large volumes to the requisite temperature. VERNON HARCOURT has, however, proved that the action of heated lime on carbon disulphide is not peculiar to that substance, but that any material exposing sufficient surface is capable of producing a similar effect, so that the action appears to be one of mere contact. An apparatus was accordingly devised by HARCOURT and C. W. SIEMENS, by which the difficulty of heating large volumes of gas continuously was overcome, the apparatus being eventually erected on a working scale at the Horseferry Road Works of the Chartered Gas Co. The method worked well for a time, the reduction in the amount of sulphide existing as carbon disulphide being considerable. After a time, however, the reduction became gradually less and less marked, becoming at length quite inconsiderable in amount, from some reason which it is by no means easy to explain; and the difficulty which then presented itself has not yet been overcome.

The cheap and efficacious removal of carbon disulphide from coal gas without nuisance is a problem which must be as yet considered unsolved, and one well worthy of the attention of inventors.

Many new schemes for the production of gas for heating and illuminating purposes have recently been introduced; but although some of them have excited considerable attention, there is at present not the least probability of the present method of gas manufacture being superseded by any new system. It will doubtless be interesting to give a short resumé of the more important schemes which have been brought before the public during the past few years.

During the year 1872 several novel schemes were started, and the respective methods of gas manufacture which they advocated tested on a commercial scale. Foremost among all was the process invented by EVELEIGH, and introduced by the Patent Gas Co., Limited; and then followed the Gas Generator Co. (PORTER & LANE'S patent), the Air Gas, and the New Gas.

EVELEIGH'S invention excited a great deal of attention, both in the scientific and in the commercial world, and was the subject of a most rigorous investigation at the hands of KEATES and ODLING, whose report was at once exhaustive and interesting. By this process the coal is carbonized at a considerably lower temperature than that usually employed, the retorts used having twice the ordinary capacity, and the distillation occupying double the usual time. A smaller yield of gas is thus obtained, which is, however, of comparatively high lighting power, and a certain quantity of oily tar, which is subsequently submitted to destructive distillation in a specially constructed apparatus, in which it becomes partially converted into permanent gas. The two distillations, that of the coal and that of the oil, are, in practice, going on simultaneously, and the resulting gases mix together during their passage to the holder. The combined result of the distillation of the coal and oil by this method is a larger yield of gas than would be obtained by the usual process, while the gas is at the same time of considerably higher lighting power, and by reason of the comparatively low heat used, the amount of sulphur compounds present is correspondingly low.

The apparatus used for the destructive distillation of the oil, and its conversion into gas, consists essentially of three vessels encased in brickwork, and so arranged that they are placed at increasing distances from the source of heat. The vessel having the lowest temperature, and into which the oil first flows, has simply the effect of vaporizing the more volatile portions, while the residue remains as pitch, which is periodically run off into moulds for sale. The heated vapour of the oil acquires a still higher temperature by passing through the second or intermediate chamber, and then enters the last or hottest vessel. This is an iron pan filled with charcoal, and heated to about 1300° Fahr. The highly heated oily vapour, during passage through the incandescent charcoal, becomes partially converted into permanent gas, which is then conducted along a pipe, where it mixes with that from the coal, the combined gases passing through the purifiers to the holders in the usual way.

Referring to the report of KEATES and ODLING, it will be seen that the highest yield of gas obtained in their experiments on this process was 10,500 feet, the lighting power being 25 candles, and the sulphur as low as six grains per 100 feet. As this result was obtained from ordinary Norfolk Silkstone coal of average quality, which by the usual method would have yielded at the utmost about 9500 feet of 16-candle gas, the result is certainly striking. Unfortunately, it is to be feared that the increased amount of plant, labour, and fuel required more than outbalance the above favourable result, and this conclusion is inevitable not only from the report already quoted, but likewise from the subsequent failure of the company itself.

The invention introduced to public notice by the Gas Generator Co., and patented by Porter & Lane, bid fair at one time to bring forth most important results, as the principle upon which it is based is one acknowledged as correct by the whole of the gas world—viz., the rapid carbonization of the coal by a continuous system, and the subsequent removal of the resulting gases as speedily as possible. Porter & Lane endeavoured to secure this end by the employment of a vertical retort containing a revolving screw. The coal was supplied continuously in small pieces from a hopper at the top, and carried by the action of the revolving screw in a comparatively thin layer against the heated sides of the retort, the carbonization being so rapid that by the time the coal reached the bottom it was converted into coke, which is received into a suitable vessel as it falls. The advantages of this process are increased yield of gas, combined with slightly higher lighting power, and a comparative freedom from sulphur compounds; but on the other hand, the coke produced is said to be friable, and of less than average quality. The greatest impediment, however, to the successful working of this process lies in the resistance offered by the coal to the free revolution of the screw, and this difficulty would appear to be almost insurmountable. The iron of which the screw is composed is, at such a comparatively high temperature, in a condition in which it is least able to bear great and long-continued strains, and it was actually found in practice that the revolving screw was so frequently being fractured that continuous working was rendered impossible.

Air Gas.—This scheme, patented by the Messrs. Harrison, possessed no novel features over many prior inventions, and consisted merely in drawing air into a holder through light petroleum spirit, when the air became sufficiently charged with the hydrocarbon vapour to enable it to burn with a brilliant light. The introducers claimed to manufacture gas with greater cheapness than could be attained by the ordinary method, while they likewise stated that the carburetted air was a permanent compound not subject to condensation, and that it would bear passing through lengths of pipe at varying temperatures without injury or loss of illuminating power. Such a statement is, however, against all previous experience, which has invariably shown that such mechanical mixtures as air and the vapour of hydrocarbons, which are in their normal state liquid at ordinary temperatures, have a constant tendency to separation, and that any reduction, or even variation of temperature, is sufficient to cause a partial deposition of liquid hydrocarbon, and consequent loss of illuminating power.

New Gas.—The invention of Ruck, characterized by the title of the "new gas," bears many points of resemblance to the well-known Water Gas of White. Ruck's process consists in the admission of steam into retorts containing coke and metallic iron heated to a high temperature. The steam, under these conditions, suffers decomposition, its oxygen being taken up by the coke to form gaseous carbonic acid, or with the metal to form a fixed oxide of iron, while the hydrogen, with which the oxygen was previously combined, becomes liberated in the free state. Part of the carbonic acid produced becomes subsequently converted into carbonic oxide by contact with the excess of carbon present, so that the gas which is eventually obtained consists of a mixture of carbonic acid, carbonic oxide, and hydrogen. The gas thus far is non-luminous, and can be used in this condition for heating purposes; to give it, however, the requisite degree of luminosity to render it suitable for illumination the usual method is resorted to, that of impregnating it with the vapour of light petroleum spirit. Relative to the permanence of the final product, it is stated by the company that the gas has been passed through considerable lengths of pipe at a freezing temperature without in the least suffering any deterioration of lighting power, a result which would, if true, be very remarkable, as ordinary coal gas of even moderate illuminating power subjected to such a test would suffer considerably. It must likewise be borne in mind that Ruck's illuminating gas is as much a mechanical mixture as Harrison's air gas, and the remarks made on the latter apply with equal force to the former. Ruck has, however, one advantage, viz., that the medium which he subjects to carburation is one which requires less petroleum spirit to give it a given degree of luminosity than such a substance as air, which, containing oxygen, consumes a large amount of the hydrocarbon vapour for the production of heat alone.

The methods recently introduced for the production of heating gas by Isham Baggs and Kid are also deserving of some attention.

Isham Baggs claimed to be able to produce good heating gas at as low a price as twopence per thousand feet, and his method consisted in the admission of atmospheric air in limited quantity into furnaces charged with coke, and built vertically. The resulting gases were taken off at the top of the furnace, and consisted of the nitrogen of the original air, together with carbonic oxide, and a little carbonic acid. By employing sufficiently tall furnaces it was stated that there was no difficulty in producing a gas almost entirely free from carbonic acid. The action which occurs during the manufacture of gas by this means is the conversion of the oxygen of the atmosphere into carbonic acid, which by contact with such a large excess of incandescent coke becomes subsequently converted into carbonic oxide. The entering air contains 20 per cent. by volume of oxygen, and this passes into the form of carbonic acid without change of bulk. This 20 per cent. carbonic acid, in changing to carbonic oxide, would have its volume doubled, so that the final result would be, assuming the decomposition to be complete, that the exit gas would contain 40 per cent. by volume of carbonic oxide, while the remaining 60 per cent. would consist of nitrogen. A gas of this composition would unquestionably possess great heating power.

The last scheme which has been proposed is that of Kid, and was described in the *Gas Journal* for May 11, 1875. The apparatus which he uses for illustration consists of a small iron vessel, which is filled with peat charcoal and provided with a small aperture on one side near the bottom, and a pipe from the top to carry off the gas. The peat charcoal having been ignited, a small jet of steam at moderate pressure is allowed to blow into the small aperture at the bottom of the vessel, and the entering steam draws in with it with sufficient air to keep up the combustion of the peat charcoal. The steam becomes decomposed during its passage through the ignited charcoal, yielding hydrogen, carbonic acid, and carbonic oxide. A further quantity of the last two gases is likewise obtained from the union of the oxygen in the entering air with the carbon of the peat charcoal, the nitrogen of the air passing forward unchanged. As the peat charcoal is consumed it is fed in from a hopper at the top of the apparatus, and according to Kid's last improvement the combustion of the charcoal is made to generate the steam used in the production of the gas. The gas itself has been analyzed by Keates with the following result:—

Carbonic oxide,	28·6
Hydrogen,	14·6
Nitrogen,	53·0
Carbonic acid,	4·0
	100·2

Keates likewise calculates that a ton of peat charcoal could be made to yield 100,000 cubic feet of combustible gas by this means.

Gas Burners.—The subject of burners, and of the most advantageous method of consuming coal gas, is one of the most important considerations, not only to the consumer, but likewise to the gas companies. Complaints are frequently made by consumers of gas, which are in reality solely due to the bad quality or inappropriate nature of the burners which they are using. A burner should not only be a good one in the ordinary sense, but it should likewise be adapted to the quality of the gas which is being consumed, as unless this be the case it is totally unfitted for use, however well constructed it may otherwise be.

A striking exemplication of the truth of these remarks occurred some time back during the trial of Eveleigh's system of gas manufacture at the Barnet Gas Works. The quality of the normal gas supply was that usually given by local companies, and probably not exceeding 15 candles, but the gas made by Eveleigh's method had an illuminating power of about 22 candles, and complaints came in from all directions about the change of supply and bad quality of the new gas, special stress being laid on its "smoking so much." Now, although Eveleigh's gas was purer and better than that supplied under the old system, yet it failed to be appreciated, owing to the fact that the burners with which the consumers were furnished were adapted for a gas of no higher quality than some 15 or 16 candles, and consequently when gas of such high illuminating value was supplied the burners were not able to consume it properly, and the excess of carbon in the gas passed off in the form of smoke, to the annoyance of the consumer.

There is but little doubt that proper attention is seldom or never paid to the relation which ought to exist between the quality of the gas supplied by a gas company and the burners used by the consumer, and that a very large percentage of the illuminating value of the gas is utterly lost by the use of bad and inappropriate burners. In the gas referees' report on the subject of "burners" (which will be extensively alluded to again), they intimated that fully *one-fourth* of the gas supplied to London is wasted from the cause just mentioned. With respect to the conditions necessary for the production of a thoroughly good burner, that is, for one perfectly adapted to the quality of the gas which it is destined to consume, and which will develop, when burning a regulated quantity, the maximum of light possible, there are three conditions which are necessary, and which may be enumerated as follows:—

1. The gas should issue from the burner at as low a pressure as is possibly consistent with the proper flow of gas.

2. The air supply should be suitably regulated, the amount of atmospheric oxygen supplied to the flame being exactly proportioned to the richness of the gas.

3. The burner should be so constructed that the gas is kept as cool as possible up to the point of its being consumed.

The reader will be better able to comprehend the conditions necessary for the construction of a good burner for the consumption of illuminating gas, if an explanation be first given of the generally received theory of the cause of the production of light during the combustion of hydrocarbons.

When a gas consisting of a combination of carbon and hydrogen is ignited in contact with a regulated supply of atmospheric air, the hydrogen of the hydrocarbon is the first to unite with oxygen, in consequence of the great affinity which it possesses for the latter element. Under these conditions the carbon with which the hydrogen was previously combined is for the moment liberated in the free state in the interior of the flame, and becoming intensely ignited, gives rise to a development of light; the carbon particles passing subsequently to the exterior of the flame, where there is a comparative excess of atmospheric oxygen, become completely burned to form carbonic acid. The ultimate products of combustion are, therefore, water from the hydrogen of the hydrocarbon and carbonic acid from its carbon.

When gas is burned with an insufficient supply of air, the flame becomes larger than it would normally be, and of a yellowish colour, owing to the carbon particles not being heated to the degree of incandescence necessary for the production of a *white* light; the combustion is likewise incomplete, and instead of the carbon being entirely consumed, much passes off in the form of smoke.

When, however, gas is consumed in contact with a proportion of air greater than that required for the full development of its light-giving power, the flame shortens, with a corresponding sacrifice of luminosity; and if the air be *largely* in excess the flame loses to a greater or less extent its white appearance, and assumes a bluish tint. Under these conditions the amount of atmospheric oxygen supplied to the flame is largely in excess of that required for the complete combustion of the hydrogen, and the surplus oxygen present unites immediately with its proportion of carbon, which being burned direct does not produce light. We may therefore assume three conditions under which gas may be burned.

1. When the supply of atmospheric oxygen is insufficient for the full development of the illuminating value of the gas.

2. In which the amount of air supplied to the flame is proportioned to the amount of carbon and hydrogen in the gas, and so regulated as to produce the maximum amount of light.

3. In which the quantity of air is in excess of that legitimately required.

The second condition is obviously that which should be aimed at in the construction of a burner intended to develop the greatest amount of illuminating value possible from the gas which it is destined to consume. The methods of regulating the quantity of air supplied to a flame differ according to the description of burner. In the batswing and fishtail the size and angle of the apertures determines the volume of air, while in the Argand the chief regulating agent is the chimney; the latter being perhaps the only description of burner in which the air supply is under complete control. With a poor gas a comparatively small amount of atmospheric oxygen is required, and the most suitable burners for consuming such gas are those with comparatively large holes. The directive force with which the gas issues is thus small in proportion to the quantity passing, and the supply of air likewise correspondingly small. Argands burners are better adapted for poor gas than Flat flame, as in the latter it is more difficult to keep the air supply sufficiently low. With a rich gas, that is, one having a high illuminating power, considerably more oxygen is required, and the most suitable burners are ones with comparatively fine apertures, whereby the directive force of the gas is increased, and with it the supply of oxygen.

The importance of constantly bearing in mind the relation which should exist between the burner and the gas has been already noticed, and for this reason it should be remembered that the maximum amount of light is being obtained alike from the burner and the gas only when the specified quantity of gas is being consumed, any amount either over or under that for which the burner is specially constructed giving an amount of light proportionately under the real illuminating value of the gas. The cause of this is almost obvious, and depends on the adjustment of the air supply. Given gas of a definite lighting power, and requiring an equally definite amount of oxygen to unite with the carbon and hydrogen present, in such a way as to develop the maximum amount of light; given likewise a burner so constructed as to exactly fulfil the necessary conditions when consuming a specified quantity of gas; and it cannot fail to be seen that any increase or diminution in the specified amount, or any variation in the quality of the gas itself, must be attended in some way with a loss of illuminating value. If the supply of gas is unduly diminished, the flame does not assume its proper shape; and in the case of an "Argand" burner the air supply becomes excessive, and the gas is "overburnt;" if, on the contrary, the gas supply is unduly increased, the air supply is often insufficient, and with an "Argand" burner much of the illuminating value is lost by the escape of unconsumed carbon. Change in the quality of the gas, the burner remaining the same, is likewise attended with similar results, the proportion of oxygen supplied being excessive when the gas is of poorer quality—that is, of lower lighting power—and insufficient when the illuminating value of the gas is to any extent increased. Owing, however, to the construction of the ordinary burners supplied to the public not being so accurately adjusted as theoretical considerations would consider desirable, variations in the quality of gas and the rate of consumption are not attended with such consequences as might be at first imagined; and there exists another source of correction of any variation in the gas, which is, fortunately, self-acting and depends on *size of flame*. When the gas is supplied to the burner at a rate exceeding the proper consumption, more air is obviously required for combustion, and this end is to a great extent attained by the *increased velocity* with which the gas issues from the burner, and the *increased volume of flame* presented to the action of the air. When likewise the amount of gas is below the proper rate of consumption, the diminished velocity with which the gas issues and the diminished size of flame both tend to give a diminished air supply. It is perhaps not desirable that for ordinary use a burner should have its equilibrium (as it might be termed) of gas and air theoretically exact, as the flame would be excessively sensitive to the least atmospheric disturbances, and the slightest draught would be sufficient to cause it to flicker and smoke. In order to confer the necessary stability to open burners, that is, to those without chimneys, it is necessary that the gas should be slightly "overburnt;" and this is in fact the case in the majority of burners supplied for public use.

The report of the gas referees, which has already been alluded to, contains some very useful and instructive information on the subject of burners; and in illustration of the remarks which have been made on the proper conditions which should exist in a thoroughly good gas burner, it will be useful to give a short *résumé* of some of their results. Firstly, then, with regard to the proportionate amount of illuminating power obtained from fishtail and batswing burners when consuming the proper quantities of gas for which they are by construction adapted, and when burning quantities of gas in excess or deficit of the specified quantity.

The experiments were made on gas of an average illuminating power of fifteen candles, tested with SUGG'S London Argand, No. 1, taken as a standard. The amount of light given in this way was called 100, the numbers in the third column being in proportion. The numbers in the fourth column of the table, showing "Illuminating Power calculated to 5 feet SUGG'S London as 100," were obtained by assuming that the light emitted by the consumption of different quantities of gas was the same, *proportionately* speaking. Thus, "supposing the tested burner gave a light of 40 per cent. (compared with the standard burner) when burning at the rate of 4 feet an hour, then instead of 40, its light is stated in the fourth column as 50, because the standard burner was consuming 5 feet an hour against the 4 feet consumed by the tested burner."

The referees' table contains the result of several experiments, but as they are in all cases similar, it will suffice to give the results of testing a single fishtail and batwing selected as good examples.

FISHTAIL BURNER.

Pressure of Gas as Delivered to Burner in tenths of an inch.	Consumption of Gas in feet per hour.	Actual Illuminating Power—Sugg's London No. 1 at 5 feet being taken as 100.	Illuminating Power calculated to 5 feet—Sugg's London as 100.
·05	1 0	6·9	34·1
·17	2·0	18·8	47·0
·26	3·0	27·6	46·1
·61	4·0	30·9	38·6
·95	5·0	31·5	31·5

BATWING BURNER.

Pressure of Gas as Delivered to Burner in tenths of an inch.	Consumption of Gas in feet per hour.	Actual Illuminating Power Sugg's London No. 1 at 5 feet being taken as 100.	Illuminating Power calculated to 5 feet– Sugg's London as 100.
·05	1·3	13·2	53 0
·10	2·2	16·4	74·8
·20	3·6	62·0	85·0
·30	5·0	86·5	86·4
·40	6 2	106·0	85·4
·50	7·2	111·2	79·4
·60	8·1	127·4	78·6

It will here be seen that, with comparatively small quantities of gas, the full illuminating value is not obtained; the ratio gradually increases with the quantity of gas, until the maximum lighting power is obtained at a point where the burner is supplied with the special quantity of gas which it is by construction properly adapted to consume; and beyond this, if the supply of gas is further increased, there is a diminution of lighting power. These results will be readily understood from the remarks previously made on the ratio which is necessary between the burner and the amount of gas. With Argand burners the result is still more striking. In the table the burners used were ordinary fairly constructed Argands, the experiments being conducted and results calculated exactly in the same way as in the experiments on fishtail and batwing burners.

ARGAND BURNER.—No. 1.

Pressure of Gas as Delivered to Burner.	Consumption of Gas per hour.	Actual Illuminating Value—Sugg's London at 5 feet being taken as 100.	Illuminating Power calculated to 5 feet—Sugg's London as 100.
·05	2·1	5·4	12·7
·07	2·8	19·5	34·2
·10	3·3	34·1	51·6
·14	4·0	60·5	75·0
·17	4·4	77·0	86·1
·218	5·0	100·0	100·0*

ARGAND BURNER.—No. 2.

Pressure of Gas as Delivered to Burner.	Consumption of Gas per hour.	Actual Illuminating Value—Sugg's London at 5 feet being taken as 100.	Illuminating Power calculated to 5 feet—Sugg's London as 100
·1	1·8	1·6	4·5
·2	2·7	7·8	14·3
·3	3·4	15·0	21·8
·4	4·2	21·9	26·0
·5	4·6	29 3	31 5
·6	5·2	34·7	34·3

In these cases it will be seen that the proportion of light given increases regularly with the amount of gas consumed, reaching a maximum when any further increase in the supply of gas would have caused smoking. It was found by the referees to be almost invariably the case for all classes of burners, but more especially for Argands, that the maximum amount of light in proportion to the gas consumed was given when the burner was on the point of smoking.

With regard to the effect of air supply on combustion and on the development of the maximum lighting power from gas, the referees made some striking experiments: and the burners used were Argands, which permitted of better management, owing to the amount of air admitting of easy regulation by alteration in the size and height of the chimney used. In these experiments there is a good exemplification of what the amount of light actually emitted by the flame of an Argand really depends on. The referees point out that the actual *amount* of light emitted depends on the volume of the flame *plus* its intensity. It is quite possible to consume gas in such a way that a large volume of flame is obtained having but little intensity. This condition generally occurs when the directive force of the gas is small and the air supply somewhat insufficient. As the directive force of the issuing gas is increased, and the air supply greater in proportion, the flame becomes smaller in volume, but whiter and more intense, the rapidity of combustion being greater and the *area* of combustion (as it may be termed) contracted. A further supply of air has the effect of further diminishing the volume of flame and intensifying the combustion; but this intensification may take place at the expense of a certain amount of the total lighting power which would be given by the same quantity of gas burned under the most favourable conditions. The referees are led to the conclusion that the maximum amount of light is obtained when there is a proper balance between the volume of the flame and its intensity, and that if, by an increased air supply, the intensity is carried beyond a certain point, that in spite of the flame being brighter there is an actual loss of illuminating power, owing to the *increased intensity* not sufficiently compensating for the *diminished volume*. There is, in fact, great probability that it is not always the whitest flames which give the highest photometric results, but those which have a slight tinge of yellow, and in which the intensity is not carried to the utmost point which might be obtainable by an increased air supply.

The following table, taken from the gas referees' report, will show at a glance the force of the above remarks, the figures in the last column being specially instructive. The "narrow band of flame" there mentioned was obtained by excluding the greater part of the flame by means of a metal plate having a horizontal aperture half an inch in depth. This slit was so regulated as to allow the light from the intense part of the flame to pass to the photometer at the same time that the light from the whole of the remainder of the flame was excluded.

SUGG'S LONDON ARGAND No. 1 CONSUMING 5 FEET PER HOUR OF 16 CANDLE GAS.

Experiments.	Size of Chimney.	Height of Flame.	Illuminating Power of Entire Flame.	Varying Intensity of the narrow band of flame.
No. 1,	Without chimney,	8 inches	66	29·3
" 2,	6 inches by 1¾	Smoked	98	82·0
" 3,	6 " 2	Smoked slightly	98·2	82·6
" 4,	6½ " 2	4 inches	98·7	83·7
" 5,	7 " 2	3·6 "	100·0	90·0
" 6,	7½ " 2	3·25 "	99·2	92·9
" 7,	8 " 2	3·0 "	96·7	94·7
" 8,	9 " 2	2·75 "	92·1	97·1
" 9,	10 " 2	2·6 "	87·9	98·9
" 10,	11 " 2	2·5 "	84·57	100·0

Other points in connection with the development of light from gas were examined by the referees. Among other things, it was incidentally noticed that those flames which gave the most light in proportion to the gas consumed were also the *hottest* flames; and this fact is explained by the referees assuming that as the light emitted by burning gas is in the main due to the incandescence of the carbon particles, that the higher the temperature to which they are during combustion subjected the greater their incandescence—the greater the amount of light emitted. The explanation which they give is in all probability correct, for it is well known that any substance capable of withstanding a high temperature will emit light when the temperature is sufficiently high, and that the light emitted increases with augmented heat. The question of the transparency of gas flames was likewise examined by the referees, who came to the conclusion that flame was only partially transparent, and that the whitest and most luminous flames were those which were most opaque to light. This conclusion is of importance in the arrangement of burners for lighting purposes; besides which, as the referees point out, the fact of the opacity of flames to light points out an inherent defect in the construction of the Argand burner, although it obviously has an advantage of another description. With flat flame burners the light must be very varying in certain positions, being especially at a minimum when the observer is in such a position that the flame is presented *edgeways;* with an Argand burner, whatever relative positions are occupied by the burner and observer respectively, the amount of light is obviously the same.

Having now discussed the general principles which should regulate the construction of gas burners, it now remains to individually describe the various descriptions in general use.

Commencing with the ordinary "fishtail," which is more largely used than any other form of burner; it derives its name from the shape assumed by the flame resembling the tail of a fish. The gas issues through two apertures inclined at such an angle, that the two currents of gas impinge against each other and spread out laterally, giving a flame at right angles to the point of exit.

The commoner varieties are constructed of iron, and vary exceedingly in quality. The superior descriptions generally have the body constructed of brass, while the top of the burner from which the gas issues is made of steatite or porcelain composition. The latter sort of burner is by far the best, as the most important portion is made of an uncorrodable material, and thus differs essentially from those constructed entirely of iron, and which rapidly become corroded.

There has never been any essential variation from the original type of the fishtail burner, although many inventors have introduced modified forms purporting to present increased advantages in the way of lighting power. In some of these modified burners, the hollow chamber of the burner is plugged with cotton wool, or small discs of fine wire gauze, the object being to lessen the pressure with which the gas issues from the burner apertures. Other burners have been specially constructed either with a view to heat the gas prior to ignition, or to keep it as cool as possible, according to the opinions of the respective inventors. A burner was introduced some time back, in which two fishtail burners were inclined so as to unite the two flames into one; none of these burners, however, have presented much gain in illuminating power, although some have given slightly better results than others. The best results to be obtained from fishtail burners with ordinary gas, is to select those with comparatively large holes, and using a governor to regulate the amount of gas passing, the burner itself being constructed of some material not liable to corrosion.

The batwing or batswing burner is also a description of burner which is in very general use, and which has received a larger share of attention at the hands of inventors than even the fishtail. The burner derives its name from the peculiar form of its flame. The aperture through which the gas escapes for combustion is a slit of varying width and diameter, depending on the quantity of gas intended to be consumed. The commoner varieties of this description of burner are generally constructed entirely of iron, the better kinds being made of brass with steatite tops.

Fig. 12.

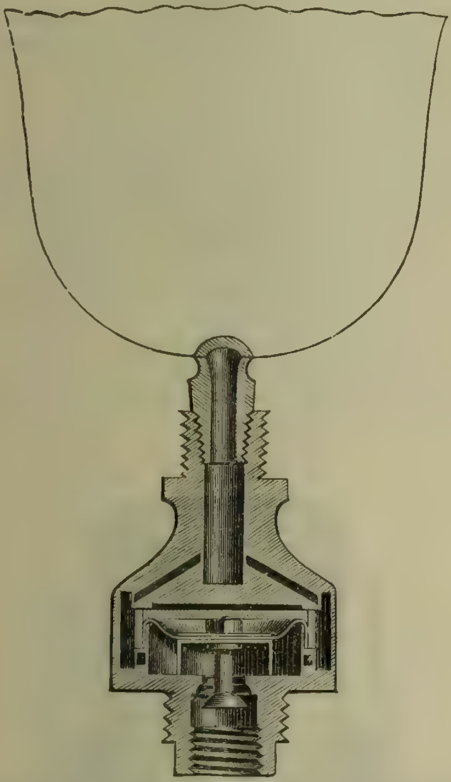


Fig. 12 represents an ordinary batwing burner, showing at the same time the characteristic shape of the flame, which, however, slightly varies with different descriptions of manufacture.

The diagram likewise shows a self-acting governor attached to the burner, and with the addition of which far better results are obtained.

The more improved forms of the "Batwing," such as the "Bronner burner," have been of late largely superseding the ordinary "fishtail" for the illumination of private houses and places of business, the advantages claimed for this special modification of burner being considerable. Figs. 13 and 14 represent this form of burner, as it is at present manufactured, Fig. 13 being a section of "Bronner's" burner as it is adapted for burning gas made from common coal, and Fig. 14 represents a "Bronner's burner" for cannel gas. It will be observed that there is a difference in the form of the top or burning orifice in these two illustrations, arising from the circumstance that the two gases are not of the same illuminating power. A feature in Bronner's burner is the facility it presents for varying the particular burner, in strict accordance with the pressure, and also in strict accordance with the quality of the gas. There are eighty-eight different modifications *for cannel gas alone*, and the well-instructed gas engineer selects from the number the exact size or kind which the circumstances of each particular case require. The principle of both burners is the same. The points of distinction between the "Bronner burner" and the other descriptions of batwing in general use is, that at the extreme base of the burner there is a small slot by which the gas is admitted to the burner chamber. This slot is intended to serve the double purpose of limiting the quantity of gas consumed by the burner, and checking the pressure of the gas prior to its final issue from the burner aperture. These burners are exceedingly good, and give a light far greater than that obtained from the ordinary varieties of fishtail.

Fig. 13.

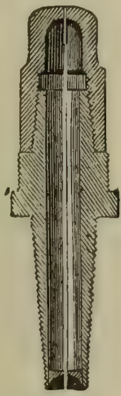
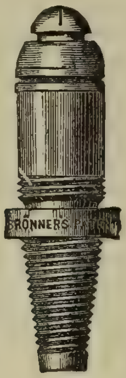


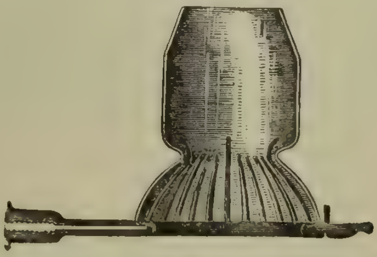
Fig. 14.



The Argand differs from all other forms of burner in having a circular form and requiring the use of a chimney. The old iron Argand was a very defective burner, with its excessively large chimney, and there is but little doubt that the air supply was excessive and the gas considerably overburnt. Fig. 16 shows the more ordinary form now given to this description of burner.

The "Leslie burner," represented by Fig. 15, was a considerable improvement. The peculiarity of this burner consisted in the gas flowing through a number of small copper tubes instead of through holes, as in the ordinary Argand. The chimney

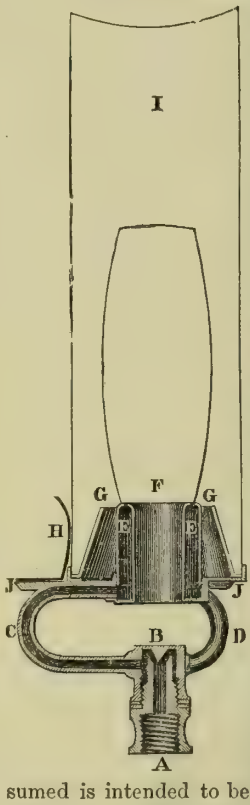
Fig. 15.



used was a comparatively low one, and this in all probability prevented the air supply from being excessive, while at the same time the peculiar manner in which the gas issued insured complete combustion.

The old iron Argand was used for testing (what was then) 12-candle gas. This was afterwards improved conjointly by Letheby and Sugg, and the improved form known as the "Sugg-Letheby" gave an increased illuminating power of 2 candles with the same quality of gas, thus virtually raising the old 12-candle gas to 14 candles. Subsequently Sugg again made improvements in the construction of the burner, the result of which was a further gain of about 2 candles in the illuminating power; so that what was formerly 12-candle gas, as measured by the old iron Argand, is now registered as equal to 16 candles by the "Sugg London Argand."

Fig. 16.



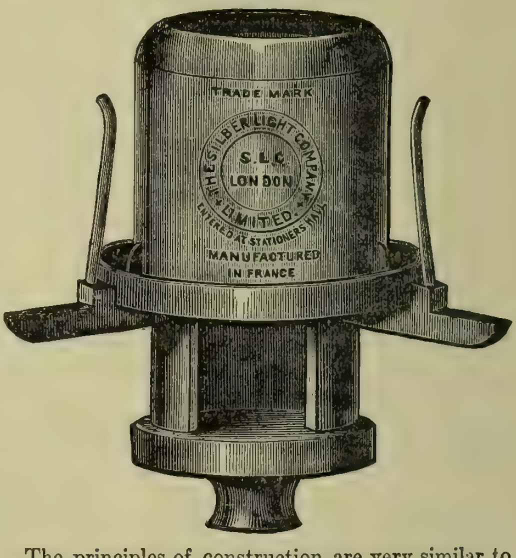
This burner, represented in Fig. 16, gives a powerful white light and well-formed flame, differing slightly in shape from that given by ordinary Argands. The special points of construction will be best understood by reference to the diagram: A is the screw-piece by which the burner is attached to the fittings. It will be seen that there is a small conical projection, B, exactly above that part of the burner at which the gas enters. When the burner is screwed firmly down, the conical projection entirely closes the gas entrance; but by giving the burner a few turns in the opposite direction, the gas is allowed to pass in proportion to the amount of unscrewing, and consequent freedom of the passage by which the gas enters. The quantity of gas passing to the burner may thus be easily controlled, and when the amount consumed is intended to be a fairly constant quantity, small paper discs may be fitted on to the screw, so that when the burner is firmly screwed down, the conical projection, B, is still sufficiently above the gas entrance to allow the desired quantity of gas to pass. The gas passes to the burner chamber, E E, by three small tubes (two of which only are shown, viz., C and D, in the Fig.). The burner is surmounted by a cone of metal, G G, which helps to regulate the quantity and direction of the air supply. The chimney, I, is supported by the lateral projections, J J, and kept in position by the spring, H. The burner is so constructed that the total area of the combustion orifices is greater than that of the three tubes which admit the gas to the combustion chamber, and the pressure of the gas at the point of ignition is therefore nil. The following dimensions of this burner have been furnished by Sugg:—

	Inch.
External diameter of steatite top, ...	0·84
Diameter of centre aperture, ...	0·47
Diameter of holes, ...	0·04
Number of holes, ...	24

This burner has been adopted by the Metropolitan gas referees as the standard burner to be used for testing the quality of the gas at the official testing stations. It is used with a 6-inch by $1\frac{3}{4}$ chimney for 14-candle gas, and 6 by 2 inches for gas of 16-candle quality. In a later form of Sugg's Argand the metallic cone is perforated with a series of holes at its lower edge, which allow a distinct current of air to circulate between the chimney and the heated products of combustion. The purpose of this arrangement is to diminish the amount of radiant heat given out by the burner, which in ordinary circumstances is considerable.

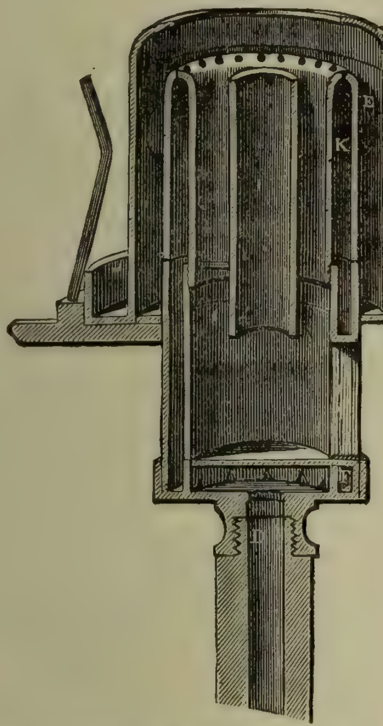
The Silber Burner.—This burner is shown in Figs. 17 and 18; Fig. 17 showing the ordinary appearance of the burner, while Fig. 18 exhibits a sectional view.

Fig. 17.



The principles of construction are very similar to the London Argand of Sugg, an external cone being used, and the pressure at the point of ignition reduced by a suitable adjustment of the comparative areas of the inlet and outlet holes. An essential feature of this form of burner, as differing from Sugg's Argand, is that of having a central tube or shaft, the function of which, according to Valentin, is to regulate the inner air draught. Referring to the sectional diagram, it will be seen that the gas enters at D, and passes by a series of holes surrounding the chamber, F, into the burner chamber, K. E is the cone which surrounds the upper part of the burner, rising to a higher level than the burner orifices, in which it differs from Sugg's burner. This burner is likewise provided with a regulating screw, to control the amount of gas passing for consumption. From a report made by Dr. Wallace, the gas examiner for Glasgow, the light which this burner gives is the same as that given by Sugg's London Argand. In Valentin's report, however, it is stated that ordinary gas which, with "the best test burners now in use in London" gave a light of from 16 to 17 candles, gave with the Silber Burner a light of from 20 to 22 candles. The exact burner used, however, for comparison is not specified.

Fig. 18.



Consumer's Governors.—With ordinary gas burners, having no special provision in their construction for moderating the pressure of the gas, it is impossible to obtain uniformly good results with varying pressures. The use of a governor or regulator is here of great service, as by its use the amount of gas passing to the burner for combustion is so moderated as never to exceed a legitimate amount, and the burner tap may be turned full on without occasioning any undue consumption of gas. Referring back to the illustration given of Sugg's patent flat flame regulating burner, Fig. 12, it will be seen that the regulation is effected by a small governor situated at the base of the burner. The action of this regulator or governor is extremely simple; the upper part is constructed of flexible leather, and in the centre of this leather is a small metal plate, to the lower surface of which is attached a metallic rod, expanding at its base into a sort of rounded cone. The gas passes to the burner between the sides of the valve cone and its seat, escaping through two lateral holes to an external chamber, and from thence to the burner. It will be seen that any excess of gas pressure over and above a certain amount will tend to more or less raise the flexible leather top, which will, by drawing up the valve cone with it, diminish the supply of gas to the burner, and thus check the pressure. This form of governor is well adapted for single burners; and can also be made, on a slightly larger scale, to affect the gas supply of a house, being fixed for that purpose at either the inlet or outlet of the consumer's meter —the inlet is the most preferable position. Street burners in the public lamps are now almost always fitted with governors, and the saving effected in this way from the prevention of excessive and wasteful consumption of gas has been found considerable. There is another form of regulator which has been more recently introduced, and which is termed "Giroud's Patent Rheometer," and of which a sectional view is here shown.

Fig. 19.

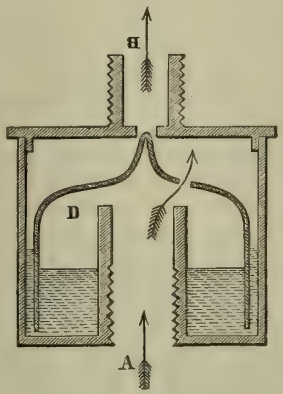
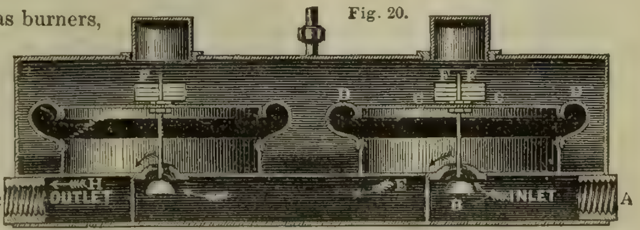


Fig. 20.



The small brass vessel forming the external case is half filled with glycerine, and the gas enters at A, then passes through a small hole in the bell, D, and finally out at B. Any undue increase in pressure causes the bell, D, to rise, and its pointed extremity, by partially closing the orifice through which the gas passes, occasions a partial check, and moderates the quantity of gas passing. For special purposes, where a greater degree of uniformity in gas consumption is necessary than is supplied by the single governor, the double form represented in Fig. 20 may be employed known as "SUGG'S Double-dry Governor." This form is extremely useful for any purpose in which the use of a portable regulating apparatus is necessary, such as in photometrical experiments.

Consumers' Fittings.—A few words on consumers' fittings may be of use here, as many misunderstandings have occurred between a gas company and a consumer on the subject of the quality of the gas supply, which with efficient fittings and good burners would never have arisen. The greatest mistake which is generally made is that of supplying gas-fittings of insufficient size; on many occasions, too, burners are placed and pipes are laid in a house in places not at first anticipated, and the then existing service-pipe is not of sufficient size to cope with the increased demand. The consequence is that an insufficient supply is obtained, the blame of which is too often placed on the gas company, and attributed to "bad gas." In laying pipes for the gas supply of a house, they should always be sufficiently large to give, necessary, an increased supply; all sharp angles and if abrupt bends should be avoided; and wherever the pipes are placed in a horizontal position they should have a slight downward slope, so that any condensed water may not accumulate so as to impede the passage of the gas. All exposed positions should be avoided, as the transition of gas from a higher to a lower temperature favours the separation of naphthaline and subsequent stoppage of the pipe; and lastly, pipes should be laid in positions where they can be readily got at, the building and cementing in of pipes, so often practised, being specially avoided. In the event of the gas supply becoming suddenly inefficient, while from the appearance of neighbouring houses and street lamps it may be judged that the supply to the *district* has not diminished, an examination should be made of the house fittings, and the pressure taken wherever possible. By this means the locality of the stoppage may readily be discovered and the evil remedied.

The following table, which has been compiled from some experiments made by Mr. ALFRED H. WOOD, of the Hastings Gas Works, will be found of use to the gas consumer.

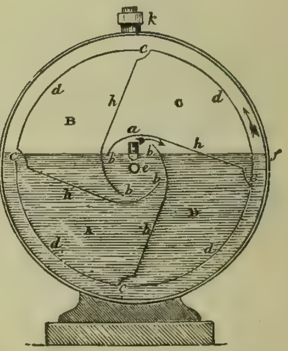
TABLE SHOWING THE QUANTITIES OF GAS IN CUBIC FEET PASSED PER HOUR BY PIPES OF DIFFERENT LENGTHS AND DIAMETERS, AT A PRESSURE EQUAL TO 1 INCH OF WATER.

Diameter of Pipe.	Length of Pipe in Feet.			
	50 Feet.	100 Feet.	150 Feet.	200 Feet.
¼ inch,..........	7·33	4·14	2·61	1·93
⅜ "	31·75	18·73	13·44	10·50
½ "	60·50	40·50	29·50	24·83
⅝ "	103·45	78 59	59·84	47·19
¾ "	150·00	114·44	97·22	84·60
1 "	253·00	208·77	184·75	160·81

It is customary to assume that the average burner for house consumption passes about five feet per hour; it is only necessary, therefore, to divide the number of feet which will be passed by a pipe of known length and diameter by five in order to obtain the number of burners which such a pipe could safely supply. The figures in the table are based on the passage of gas through perfectly straight lengths of pipe, and it is obvious that where many angles and bends occur, the amount of gas which a pipe would pass under a definite pressure would, by the increased friction, be proportionately diminished. It will therefore be necessary to make allowance for this in using the table for any practical purposes.

Consumers' Meters.—Consumers' meters are of two kinds, the wet and the dry; the former of these consists of one hollow drum or cylinder, revolving about a horizontal axis within another hollow drum or cylinder, the inner drum being divided into compartments for measuring the gas, and revolving in water, which occupies the lower part of the outer cylinder to a height above the axis about which the inner drum revolves. The details of the construction may be varied, but wet gas meters have this common feature, that the gas is measured in the compartments of a drum, which compartments are occupied successively by gas and water, the drum being made to revolve by the pressure or elastic force of the gas acting on the compartments of the drum in succession. The revolutions of the drum being registered by suitable apparatus, the quantity of gas which has passed through the meter, by so filling the compartments in succession, will be accurately registered.

Fig. 21.



In Fig. 21 the outer circle represents the outer case or drum of the meter, within which a drum divided into compartments, A, B, C, D, revolves about a horizontal axis, *e*. The gas to be measured is brought into the meter by a pipe passing horizontally in the direction of the axis of the inner and outer cylinder, and turned up at the end, so that its orifice, *a*, may stand above the water level, *f*, *g*. The four compartments, A, B, C, D, are similar in every respect, each having an inlet, *b*, by which the gas enters the compartment, and an outlet, *c*, by which it passes out of the compartment into the upper part of the outer case, whence it may pass by a pipe, *k*, in any convenient direction. The gas being admitted into the meter, will pass the inlet, *b*, into the part of the compartment, D, which is just rising out of the water; the gas presses equally on the surface of the water and on the side, *h*, of the compartment, D; the effect of this pressure on the side, *h*, is to cause the inner drum to revolve, whereby the compartment, D, is raised more and more out of the water, and as it rises it fills with gas, until it occupies, by the revolution of the drum, the position in space of the compartment, C, as to which it will be observed that the inlet, *b*, has just dipped below the surface of the water, and the outlet, *c*, is just coming to the surface of the water. The outlet, *c*, having risen above the surface, the gas will escape into the upper portion of the outer case. As the gas passes out of a compartment in the situation of C, by the outlet, *c*, water will enter by the inlet, *b*; and as the drum revolves the compartment D having occupied the position in space of C and B, comes into the position A, when it is entirely emptied of gas and filled with water, until, by further revolution of the drum, the compartment having come again into the position of D begins to fill with gas, as already described. That which has been described for one compartment takes place for the other three, and it will be seen that there will always be two compartments discharging their gas into the outer case above the water level, one compartment filling with gas, and as it fills causing the inner drum to revolve, and one compartment full of water. The motive power, causing the inner drum to revolve, is the pressure of the gas in the mains, as transmitted from the gas holder at the gas works, and the quantity of gas will be ascertained from the number of compartments which have been filled and emptied, that is, from the number of revolutions of the inner drum, which are registered by a train of wheel work and a dial plate in the usual manner. The gas so measured and passed through the meter is conveyed to the burners by a pipe communicating in any convenient manner with the outer case, and the action of the meter is suspended when the gas does not pass away. The way in which the gas enters the measuring compartments of the inner drum will be better understood by reference to Fig. 22, where *b* and *c* are the extremities of a short pipe, by which the gas passes into the drum of the meter and fills the compartment *c*, which is in connection with the measuring chambers. The manner in which the revolutions of the drum are made to affect the train of wheelwork, which indicates the amount of gas consumed, is shown in Fig. 23. The spiral worm, *u*, is fixed on to the axis of the drum, and works into a wheel, the spindle of which passes through a tube which is sealed by dipping under the water contained in the case.

Fig. 22.

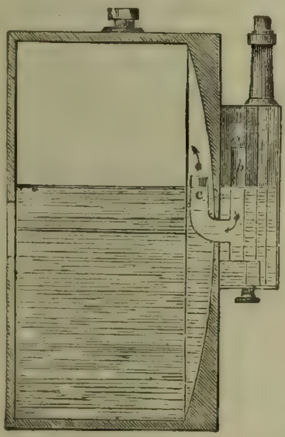


Fig. 23.

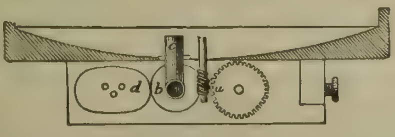


Fig. 24.

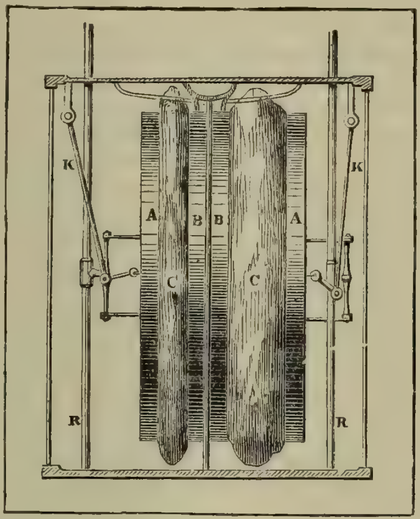
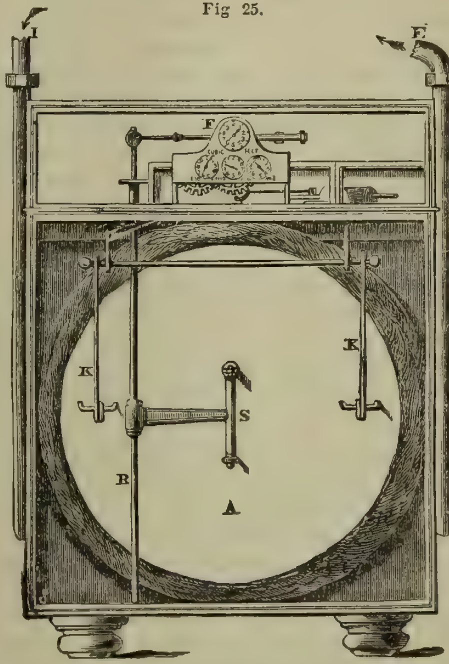


Fig 25.



The dry meter is so called inasmuch as its work of measurement is accomplished without the agency of water, the measuring chambers being of metal and leather, so combined as to open and shut very much in the same way as a bellows. The construction of Glover's meter is shown in Figs. 24 and 25. The diaphragms, as the measuring chambers are termed, are two in number, and arranged base to base. The admission and exit of the gas is so regulated by suitable valves that the expansion and contraction of the diaphragms is alternate, and the passage of gas is thus as it were continuous. The movements of the diaphgrams are communicated by means of levers to a train of wheelwork which registers the amount of gas passing in the same way as the ordinary wet meter.

The wet meter and the dry both have their respective advantages and disadvantages. In the case of the ordinary forms of wet meter the greatest disadvantage arises from the variation of the water line. It is obvious that the accuracy of the instrument as a measure depends almost wholly on the water line being preserved at a uniform height, any variations in this respect increasing or diminishing the capacity of the measuring chambers. In order to guard against an abnormal water level in either the direction of deficit or excess, it is customary to have an arrangement for preventing such undue variations. An overflow pipe, connected with a waste-box, prevents the meter being filled above a certain level, while to provide for any error in the opposite direction the meter is provided with a float attached to a valve through which the gas enters; should the water line sink below a certain level, the falling of the float closes the valve, and the gas is shut off. The consumer is thus unpleasantly warned of something being wrong by the stoppage of his gas supply, and it is not until addition is made to the water in the meter to a sufficient extent to raise the float and open the valve that the gas will again pass. A form of meter which to a great extent obviates this inconvenience is the compensating or unvarying water line meter, in which the simplest contrivance is that of having a small cistern of water attached gas tight to the meter case, and in reality forming part of the meter; a metal scoop of sufficient length is attached to the spindle of the measuring drum, and so arranged that at every revolution a small quantity of water is raised by the scoop and flows into the measuring part of the meter, the excess flowing off through the overflow-pipe, and running back again into the supplementary cistern. The water in the measuring part of the meter is thus kept at one unvarying level, and accurate measurement insured. The wet meter should be placed at the lowest part of the fittings, in order that water condensing in any part of the pipes may flow back into it. It should also be set perfectly level, as by tilting on one side unregistered gas may pass. The dry meter is free from all the previous sources of error and inconvenience, and may be placed in any part of the house. It is, however, a generally received opinion, that the contraction and expansion of the leather portion of the diaphragms is not always equal, the softness and flexibility of the leather being influenced not only by age but by temperature, a higher temperature increasing the registering capacity, while a lower one diminishes it by making the leather more rigid.

Gas as a Source of Heat.—Space will not permit of much attention being devoted to the numerous applications of coal gas for heating purposes. As an economical and efficacious source of heat for domestic purposes, &c., gas cannot be excelled, and its cleanly nature and readiness of application are considerations of great value. There is a certain amount of popular prejudice against the more extensive use of gas for cooking purposes, but this will no doubt be overcome in due course. The allegation that meat cooked by gas has an unpleasant taste is strictly untrue where proper precautions have been adopted in the cooking. Stoves should be chosen which have contrivances for regulating and keeping in the heat, at the same time that the empyreumatic products developed during roasting processes have a free escape; by this means it is impossible for the cooked meat to acquire any but its normal flavour. Gas has recently been used for heating small steam boilers, and has been found economical and efficacious, a special arrangement of the Bunsen or air burner being used. Gas is likewise much used for small furnaces, which are used with a blast of air, and in the best forms of which a great degree of heat can be obtained. For further information on the *domestic* uses of coal gas we may refer the reader to an excellent little pamphlet by Magnus Ohren, of the Lower Sydenham Gas Works.

Estimation of the Specific Gravity of Gas.—Although the mere determination of the specific gravity of gases is of very little use as a test of their commercial value—unless the gas is to be used for aeronautic purposes—yet, as it is still much employed by gas engineers, and as such an estimation is occasionally useful for controlling the results of chemical analysis, a method by which such a determination may be made is here subjoined.

The specific gravity of gases should be taken in a room where there is no fire, and where the temperature is liable to little variation during the time occupied in the operations. The following apparatus is necessary: First, a thin glass globe, capable of holding at least 200 cubic inches, and furnished with a brass cap and stopcock, so accurately fitted as to prevent all ingress of air when the globe is exhausted; secondly, a small exhausting syringe or air-pump, to which the globe can be screwed airtight; thirdly, a balance capable of weighing to one-fiftieth of a grain, when loaded with a quarter of a pound in each pan; fourthly, a glass tube, 18 inches long and half an inch in diameter, filled with fragments of fused chloride of calcium, and closed at each end with a perforated cork, through which passes a glass tube, of such dimensions as to admit of adaptation by means of caoutchouc tubing at one end, to the exit pipe of a small gas-holder, and at the other, to the stopcock of the glass globe.

The process consists in ascertaining the weight of equal volumes of atmospheric air and of the gas under examination, at the same temperature and pressure. This is accomplished by first thoroughly exhausting the globe by means of the syringe or air-pump, and then accurately ascertaining its weight, care being taken to allow time for the globe to assume the same temperature as that of the surrounding air. The globe should then be connected with one extremity of the chloride of calcium tube by means of a piece of vulcanized caoutchouc tube, and the stopcock being then very slightly opened, the air passing through the chloride of calcium, and thus being thoroughly deprived of moisture, should be allowed slowly to fill the globe. The latter being detached from the desiccating tube is replaced in the balance, where it should remain undisturbed for at least five minutes, when the stopcock is opened for a moment to equalize the pressure within and without, and the weight then accurately determined. The difference between the two determinations gives the weight of the air inclosed in the globe. The desiccating tube should now be attached to the exit pipe of the gas-holder, and a stream of gas allowed to rush through it until every trace of air has been expelled from the interstices of the chloride of calcium; the globe, again exhausted, is then to be attached to the other extremity of this tube, and the stopcock being slightly opened as before, the gas, perfectly dried in traversing the fragments of chloride of calcium, is permitted slowly to fill the globe, which should, whilst still attached to the drying tube, be allowed to stand undisturbed for a few minutes near the balance, before the stopcock is finally closed and detached from the drying tube. The weight of the globe thus filled with gas is ascertained, and that of the exhausted globe being subtracted from it, the difference indicates the weight of the gas. The weight of equal volumes of gas and atmospheric air at the same temperature and pressure having now been ascertained, it only remains to divide the former by the latter to know the specific gravity of the gas. Thus, suppose the weight of the exhausted globe to be 2000 grains, that of the globe filled with dry air 2060, and with dry gas 2040 grains, the weight of the volume of air equal to the contents of the globe would be 60, and that of the same volume of gas 40 grains; hence, $40 \div 60 = \cdot 6666$, the specific gravity of the gas, air being taken as unity.

Unless a number of specific gravities are determined at the same time, it is indispensably necessary to ascertain the weight of the air contained in the globe previous to each determination. Care should be taken that the temperature of the room in which the balance is placed does not vary more than about 1° between the several weighings of the globe, as otherwise a considerable error will be introduced into the experiments. The globe should also be protected as much as possible from the heat radiating from the body of the operator during the several weighings.—Clegg.

A very ready method of estimating the specific gravity of coal gas is by means of what is termed the "effusion test." This, originally introduced by Bunsen, has been subsequently modified by Schilling, and a convenient form of the latter description of apparatus is made by Messrs. Wright of Westminster. A description of the method, as applied to gases generally, will be found in Bunsen's "Gasometry," to which, also, reference should be made for data respecting the systematic analysis of gases.

Bromine Test.—The condensation which gas undergoes when subjected to the action of bromine was formerly much used and relied on as a means of ascertaining the comparative poorness or richness of coal gas in luminiferous constituents. The mode of applying the test is as follows:—A Cooper's tube is filled with the gas to be examined, and any carbonic acid present absorbed by means of caustic potash solution. The potash solution being then displaced, and clean water substituted, an excess of bromine water is introduced, the tube being well agitated in order to bring the bromine vapour into intimate contact with the gas. The excess of bromine is then absorbed by caustic potash, and the temperature of the gas being equalized by immersing the Cooper's tube into cold water, the diminution in volume which the gas has suffered can be read off. The bromine test is a fairly good criterion of the percentage of heavy hydrocarbons present in coal gas; but it, of course, indicates merely the amount, without revealing their nature and constitution, which is more important than the actual quantity. The results obtained in practice are, however, tolerably good.

Parliamentary Regulation of Gas Supply.—In order that the gas manufactured by gas companies, and supplied by them to consumers, shall be of good quality as regards illuminating power and purity, it is customary in most cases to impose certain conditions on the companies by means of special Acts of Parliament. In the case of London, which may be taken as a good type of gas legislation generally, the companies are under the strictest control, not only with regard to illuminating power and purity, but likewise in respect to financial and other conditions which need not receive attention here. At the present time the standards of lighting power in the metropolis are 14 and 16 candles, the conditions of purity being regulated by the facilities possessed by the respective companies for the removal of impurities. The general regulations are, however, much the same for all; the distinctive features of each Act being more special than general. It may be here interesting to give a short *resumé* of gas legislation in London, before giving a description of the present regulations under which gas is now supplied. The Gas Works Clauses Act of 1847, subsequently in great measure repealed by the Gas Works Clauses Act, 1871, did not define any conditions of purity or lighting power, and it was not until the passing of the Metropolis Gas Act of 1860 that any limitations as to quality were imposed on the companies. In the last named Act one of the leading features of legislation was the districting of the whole of London into limited areas, which were to be definitely supplied by the different companies, thus abolishing the hitherto prevailing system of competition. It was at the same time enacted that the illuminating power of the gas supplied by all the metropolitan companies should give a light of not less than 12 sperm candles of six to the pound, each candle burning 120 grains of sperm per hour, the gas to be consumed at the rate of 5 cubic feet per hour from an Argand burner with fifteen holes, and a 7 inch chimney. The presence of sulphuretted hydrogen was at the same time prohibited, and likewise the presence of "sulphur" to any extent exceeding 20 grains per 100 cubic feet.

Local authorities were likewise empowered to appoint competent persons as gas examiners, and to provide the necessary apparatus for testing. Any deficiency on the part of the company in complying with the prescribed conditions of quality was to be visited by a heavy fine. In the City of London Gas Act, 1868, most of the regulations of the 1860 Act relative to the quality of the gas supply, so far as they related to the city of London, were repealed and superseded.

The Act of 1868, which, with respect to the clauses relating to quality, has been taken as the basis of subsequent legislation, provides for the appointment by the Board of Trade of three competent and impartial persons, to be called gas referees, whose duty shall be to inspect the works of the different companies, and from time to time fix the maximum amounts of impurity which shall be allowable in the gas supplied. The gas referees have also to prescribe the apparatus to be used in testing the gas, and the special burner to be adopted. The 1868 Act also provides for the appointment of gas examiners by the local authority, and also for the election by the Board of Trade of a chief gas examiner, to whom the gas companies have the power of appeal in the event of their feeling aggrieved by the report of any of the official gas testers. The standard of illuminating power was enjoined as 16 candles, and the presence of sulphuretted hydrogen prohibited, other conditions of purity being left under the control of the referees. The Chartered, or Gas Light and Coke Company, is now under the Acts of 1860 and 1868, while the other metropolitan companies are mainly regulated by special Acts, in which the clauses of the 1868 Act, as to quality and mode of testing, have been in great measure adopted. The only exceptions are in the case of a few companies who have not recently come before Parliament, and whose gas is not under regulated official control. These companies are the Phœnix, the London, and the Surrey Consumers; the remaining metropolitan companies, viz., the Chartered, the Imperial, the South Metropolitan, the Ratcliffe, and the Commercial, are all under the direct official control of the Metropolitan Board of Works and the corporation of the city of London, and have testing stations and gas examiners, by whom the gas is daily examined. The standards of illuminating power are 16 candles for the Chartered, Commercial, and Ratcliffe, and 14 candles for the remaining companies. The maximum amount of sulphur allowable ranges from 15 to 25 grains per 100 cubic feet, according to the limits within which the various companies may reasonably be expected to work, the ammonia being limited in all cases to a maximum of 2½ grains per 100 feet.

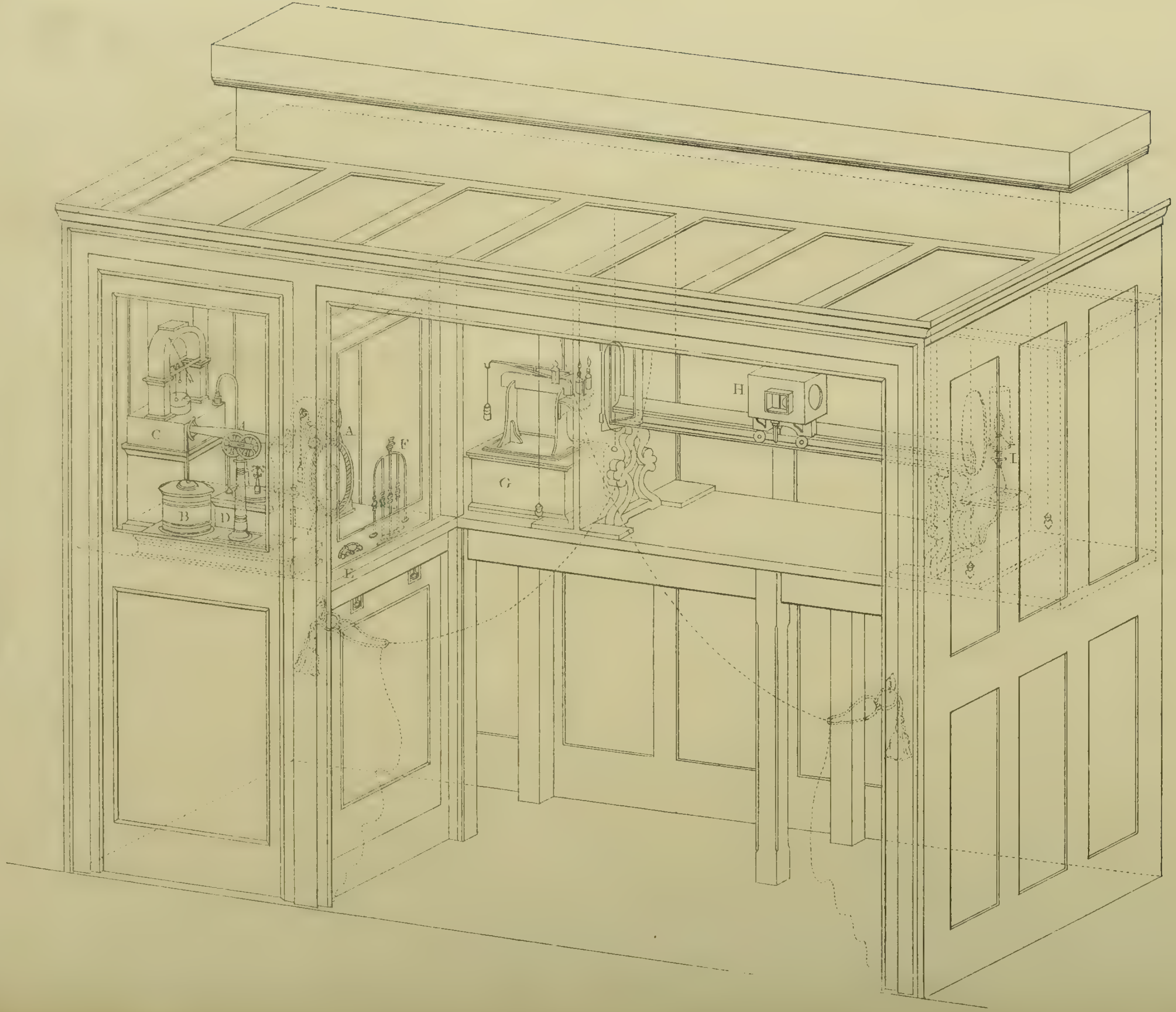
The penalties liable to be incurred by the companies, by deficient quality in the gas supply, is as follows:—For the presence of sulphuretted hydrogen, £50 for every night at each station from which the impurity is reported. For an excess of sulphur or ammonia above the prescribed limits, a similar fine. And in the case of deficiency of lighting power, £1 for every half candle deficient on every 100,000 cubic feet of gas sent out.

In speaking of the different companies, the Chartered and Imperial have been spoken of as distinct companies, whereas they have recently become amalgamated. The same is true of the Commercial and the Ratcliffe, who have recently effected an amalgamation. The South Metropolitan are also now seeking powers to amalgamate. The recent application of these companies to Parliament has been made the opportunity of further legislation, in which the prominent feature is that of having the gas examined for quality during the whole of the day, instead of in the evening only, as heretofore. Pressure will be also made an important detail, for which the companies will be subject to penalty in case of deficiency.

GAS TESTING.—*Illuminating Power—Photometry.*—For measuring the illuminating value of gas, some form of the photometer is usually employed. That adopted by the gas referees, and used at the official testing stations, is the Evans' closed photometer, which enables a comparison to be made between two lights, irrespective of any illumination of the room in which the instrument is situated. From the earliest time at which attempts were made to estimate the amount of light emitted by a body during combustion, the method used has been of necessity comparative rather than absolute, some source of light of comparatively fixed intensity being taken as a standard. The earliest method of measuring the comparative intensity of two sources of light was by observing the corresponding intensity of the shadows which were produced by the interposition of an opaque body. The method of Count RUMFORD, one of the earliest experimenters in this branch of inquiry, was that of having an upright stick of about the thickness of a pencil placed before a screen, on to which its shadow fell. The two lights to be compared being placed at some distance from the stick, a shadow of the stick was produced by each light which varied in intensity with the respective power of the two lights. The light which produced the weaker shadow was then brought nearer to the stick until the shadow thrown by each light was equal in intensity, and the distances of the lights from the stick being measured, the square of the respective distances represented the proportion between the two lights; thus, supposing the distances were 3 feet and 6 feet respectively, then the squares of these numbers would be 9 and 36, and one light would be five times as intense as the other. This method was, however, in spite of several slight modifications in the mode of working, crude and inconvenient, and the modern forms of photometer are a great improvement, although they still leave much to be desired. The photometers now in use which depend on the shadow principle are those known as the Letheby or bar photometer, and the Evans or closed photometer. The former instrument requires that all light shall be carefully excluded from the testing room while in use, while the latter, having the lights and working portions

GAS.

LETHEBY'S PHOTOMETER.



A *Meter & Meter Clock. combined.*
B *Balance, Governor.*
C *King's pressure gauge.*
D *Apparatus for Sulphuretted Hydrogen test.*
E *Regulating Cock.*

F *Connections (various) to pressure gauge.*
G *Keate's Candle balance.*
H *Photometer Bar and Sighting Box.*
I *Standard Gas Burner.*

J. B. LIPPINCOTT & CO PHILADELPHIA

inclosed in a box, needs no precautions in the way of excluding exterior light. The Letheby photometer, Plate II. (this Plate is a representation of a complete photometric apparatus recently constructed by WILLIAM SUGG, for the government of the dominion of Canada, to be used for official purposes, it differs only from that adopted by the Metropolitan Gas Referees in being inclosed, and so forms its own dark room), consists of an open bar of wood, fixed on suitable supports, and graduated from the centre to each end in such a way that the divisions of the scale indicate at once the number of times which the light used for comparison exceeds in intensity the light which is being tested. At each end of the bar are suitable supports for the two lights, while on the bar itself is a small box mounted on wheels, so as to move along the bar freely, and provided at the lower part with a small pointer, which, as the box is moved, passes over the graduations of the bar. It is by means of this box that the comparison between the lights is effected. In the middle of this box, and set vertically, is fixed a round paper disc, made semi-transparent by being saturated with melted spermaceti or paraffin. This disc is made up of three layers of paper, the middle of which has a circle or star cut from its centre, so that when the layers are placed together the central part is more transparent than the surrounding portion. An oblong hole on each side of the box allows the light from each end of the photometer to fall on the disc, while an orifice in front enables the observer to examine each side of the disc. In order to still further facilitate observation, two small vertical mirrors are arranged at the back of the box, at such an angle that the reflection of each side of the disc can be seen at the same time by the observer stationed in front, and a comparison thus made of their respective intensities. When the disc is illuminated by a source of light on each side, and the reflections from the mirrors observed, it will be seen that the central and most transparent portion of the disc appears brighter on the one side than on the other. If the box be then moved to the right or to the left, as the case may be, a point will at length be reached at which the reflections from each side of the disc appear equal in intensity, and the transparent central portion of the disc will have almost, if not totally, disappeared. The pointer attached to the box will then indicate the number of times which the one light exceeds the other in intensity.

In the Evans closed photometer the disc is immovably fixed in the centre of the photometer, the light, the intensity of which is to be estimated, being fixed at one end. The light or lights used for comparison are movable, and in estimating the intensity of any source of light the comparison light is shifted away from or moved towards the central disc until the reflections from each side appear equal. In order to facilitate working with the instrument, a handle enables the operator to move the comparison light, at the same time that he observes the reflections from the disc. The instrument, like the bar photometer, is graduated, the scale, however, commencing from each end and terminating at the centre. It is generally supported on a table by four legs, two at each end, the space underneath the photometer being devoted to accessory apparatus, such as meter, balance governor, pressure gauge, &c. Whichever form of photometer is used the method of testing and of calculating the results is the same. The source of light used for comparison is generally that which has been adopted by the legislature and specified in all Acts of Parliament relating to gas testing, viz., the standard sperm candle of six to the pound, and consuming as nearly as may be 120 grains of sperm per hour. It is assumed that the amount of light given out is in exact proportion to the quantity of sperm consumed, so that any deviations from the normal consumption can be easily corrected by a simple calculation. The gas to be tested is consumed at the rate of 5 feet per hour in a standard burner, which for common 14 or 16 candle gas is SUGG'S London Argand, No. 1, and for cannel gas of about 20-candle power is SUGG'S No. 7 steatite batswing. The Plate will give a very good idea of the arrangement of apparatus needed to test the illuminating power of gas. The apparatus used in the London official testing stations chiefly differs from that shown in having an Evans closed photometer in place of the Letheby form.

In making a test the first necessary proceedings are to adjust the gas to the parliamentary consumption of 5 feet per hour, and to have the candles burning clearly, with well-formed flames and glowing tips to the wicks. In adjusting the gas to the required quantity the regulating cock and quadrant (E in the Plate) is used, the amount of gas actually passing to the burner being shown by the meter A. The dial of this meter is graduated, and is provided with two long hands, both of which work from the centre of the dial-plate; one of these hands is in connection with the meter, while the other is actuated by clockwork, and performs an entire revolution in a minute. The construction of the meter is such, that the meter hand and minute travel together at an equal rate when the proper quantity of 5 cubic feet of gas per hour is being passed. The meter dial has also on its surface two small graduated circles, provided with indicator hands, one circle being divided into 12 parts, and indicating the consumption of 1 cubic foot of gas, the other circle in connection with the meter clock, and divided into ten divisions of one minute each. The gas having been adjusted to the normal rate of consumption, and the candles burning well, the meter clock is stopped, and by means of the string attached to the winding-up arrangement, the small hand of the dial is brought to zero. The candle balance, G, is then so adjusted that the weight slightly preponderates on the candle side, and when the balance turns over the meter clock is started, and a 40-grain weight dropped into the balance pan. Photometric observations are then made every minute, and as the completion of the tenth minute approaches the candles are watched. When the balance again turns over, which takes place when 40 grains of sperm have been consumed, the meter clock is stopped, and the time which the candles have taken in consuming the 40 grains of sperm noted. If this time is either below or above the normal ten minutes, a correction must be made for the increased or diminished consumption. Thus supposing the 40 grains of sperm have taken ten minutes and twenty seconds in consumption, then

$$10' \, 20'' :: 10' :: 40 : x \quad . \quad . \quad x = 38{\cdot}6 \text{ grains,}$$

the corrected amount. To arrive at the illuminating power of the gas, the ten-minutely observations are added up, and the mean of them taken; the result multiplied by half the corrected consumption of sperm (as *two* candles were taken for comparison) will give the illuminating power of the gas. To obtain a truly correct result, it is necessary to make a correction for temperature and pressure, in which the gas is brought to a standard of 60° Fahr. and 30 inches barometer. This result is easily attained by reference to the annexed table, where combinations of different temperatures and pressures are represented by certain figures or tabular numbers:—

TABLE TO FACILITATE THE CORRECTION OF THE VOLUME OF GAS AT DIFFERENT TEMPERATURES AND UNDER DIFFERENT ATMOSPHERIC PRESSURES.

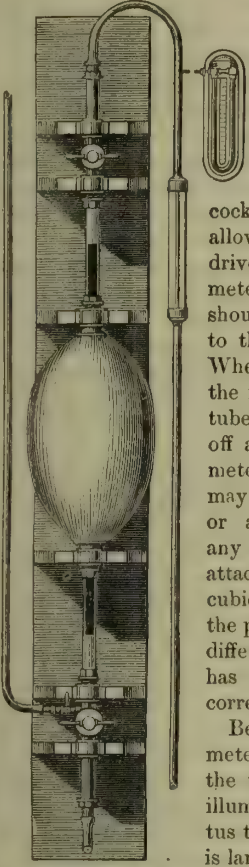
Bar.	Ther. 40°	Ther 42°	Ther. 44°	Ther. 46°	Ther. 48°	Ther. 50°	Ther. 52°	Ther. 54°	Ther. 56°	Ther. 58°	Ther. 60°	Ther. 62°	Ther. 64°	Ther. 66°	Ther. 68°	Ther. 70°	Ther. 72°	Ther. 74°	Ther. 76°	Ther. 78°	Ther. 80°
28·0	·971	·967	·963	·960	·956	·952	·948	·944	·941	·937	·933	·930	·926	·922	·919	·915	·911	·907	·904	·900	·897
28·1	·974	·970	·967	·963	·959	·955	·952	·948	·945	·941	·937	·933	·929	·926	·922	·919	·914	·911	·907	·904	·900
28·2	·978	·973	·970	·968	·963	·959	·955	·951	·947	·944	·940	·936	·933	·929	·925	·922	·917	·914	·911	·907	·903
28·3	·982	·977	·974	·970	·966	·963	·958	·955	·951	·947	·943	·940	·936	·932	·929	·925	·921	·917	·914	·911	·906
28·4	·985	·980	·978	·973	·970	·966	·962	·958	·954	·951	·947	·943	·939	·936	·932	·928	·924	·920	·917	·914	·910
28·5	·988	·984	·980	·978	·973	·970	·965	·961	·958	·954	·950	·946	·943	·939	·935	·932	·927	·923	·920	·917	·913
28·6	·992	·987	·984	·980	·976	·973	·969	·965	·961	·957	·953	·950	·946	·942	·939	·935	·931	·927	·923	·919	·916
28·7	·995	·991	·987	·983	·980	·976	·972	·968	·964	·961	·957	·953	·949	·945	·942	·938	·934	·930	·926	·922	·919
28 8	·998	·995	·991	·987	·983	·980	·976	·971	·968	·964	·960	·956	·952	·949	·945	·941	·937	·934	·929	·925	·922
28 9	1·002	·998	·994	·991	·987	·983	·979	·975	·971	·968	·963	·960	·956	·952	·948	·944	·940	·937	·933	·928	·925
29·0	1·006	1·001	·998	·994	·990	·986	·982	·978	·974	·971	·967	·963	·959	·955	·952	·948	·943	·940	·936	·932	·928
29·1	1·009	1 004	1·001	·998	·993	·989	·985	·982	·978	·974	·970	·966	·962	·959	·955	·951	·947	·943	·939	·935	·932
29·2	1·012	1·008	1·004	1·001	·997	·993	·989	·985	·981	·977	·973	·969	·966	·962	·958	·954	·950	·947	·942	·938	·935
29·3	1·016	1·011	1·007	1·004	1·000	·996	·992	·988	·984	·981	·977	·973	·969	·965	·961	·957	·953	·950	·946	·941	·938
29·4	1·019	1·015	1·011	1·008	1·004	1·000	·996	·992	·988	·984	·980	·976	·972	·969	·965	·961	·956	·953	·949	·945	·941
29·5	1·023	1·018	1·014	1·011	1·007	1·004	1·000	·995	·991	·987	·983	·979	·975	·971	·968	·964	·960	·956	·952	·948	·945
29·6	1·026	1·022	1·018	1·015	1 010	1·006	1·002	·998	·994	·991	·987	·982	·979	·975	·971	·967	·963	·959	·955	·952	·948
29·7	1·030	1·025	1·021	1·018	1·014	1·010	1·006	1·002	·997	·994	·990	·986	·982	·978	·974	·970	·966	·962	·959	·955	·951
29·8	1·033	1·029	1·025	1·022	1·017	1·013	1·009	1·005	1·001	·997	·993	·989	·985	·981	·977	·974	·970	·966	·962	·958	·954
29·9	1·037	1·032	1·028	1·025	1·021	1·017	1·013	1·009	1·004	1·001	·997	·992	·989	·985	·981	·977	·973	·969	·965	·961	·957
30·0	1·040	1 036	1·032	1 028	1·024	1·020	1·016	1·012	1·008	1·004	1·000	·996	·992	·988	·984	·980	·976	·972	·968	·964	·961
30·1	1·043	1·039	1·035	1·032	1·028	1·023	1·019	1·015	1·011	1·007	1·004	·999	·995	·991	·987	·983	·979	·975	·972	·968	·964
30·2	1·047	1·043	1·039	1·035	1·031	1·027	1·023	1·019	1·015	1·011	1·007	1·003	·998	·994	·990	·987	·983	·979	·975	·971	·967
30·3	1·051	1·047	1 043	1·039	1·034	1·030	1·026	1·022	1·018	1·014	1·010	1·006	1·002	·998	·994	·990	·986	·982	·978	·974	·970
30·4	1·054	1·050	1·046	1·042	1·038	1·034	1·029	1·026	1·021	1·017	1·013	1·009	1·005	1·001	·997	·993	·989	·985	·981	·977	·974
30·5	1·058	1·053	1 050	1·045	1·041	1·037	1·033	1·029	1·025	1·021	1·017	1·012	1·008	1·004	1·000	·997	·993	·989	·984	·980	·977
30·6	1·061	1·056	1·053	1·049	1·045	1·040	1·036	1·032	1·028	1·024	1·020	1·016	1·012	1·008	1·004	1·000	·996	·992	·988	·984	·980
30·7	1·064	1·060	1 056	1 052	1·048	1·044	1·040	1·036	1·031	1·027	1·023	1·019	1·015	1·011	1·007	1·003	·999	·995	·991	·987	·983
30·8	1·068	1·063	1·060	1·056	1·051	1·047	1·043	1·039	1·035	1·031	1·027	1·022	1·018	1·014	1·010	1·006	1·002	·999	·994	·990	·986
30·9	1·072	1·067	1·063	1·059	1·055	1·051	1·046	1·043	1·038	1·034	1·030	1·026	1·022	1·017	1·014	1·010	1·006	1·002	·997	·993	·990
31·0	1 075	1·070	1·067	1·063	1·058	1·054	1·051	1·046	1·042	1·037	1·033	1·029	1·025	1·021	1·017	1·013	1·009	1·005	1·000	·996	·993

In order to make the necessary correction of the gas, it is only necessary to find the tabular number corresponding to the observed temperature and pressure, and divide the illuminating power by the number so found. It will be seen by referring to the Plate of photometric apparatus that after the gas leaves the meter, it passes through a balance governor, B, before its final exit by the burner; this provision is necessary in order to guard against inequalities of pressure, which would more or less interfere with the uniformity of the photometer readings by variations in the rate of consumption.

At the official testing stations, where correctness in the apparatus used is of vital importance, provision is made for checking the accuracy of the meters used by means of an apparatus called "the cubic foot test," Fig. 26. This consists essentially of a vessel made of block tin, and having a capacity of exactly 1 cubic foot.

By means of suitable connections water may be admitted to the measure, which, being placed in communication with the meter to be tested, allows the expelled air to pass through the meter. The cubic foot test having filled with water, it is known that exactly 1 cubic foot of air has passed through the meter; should the meter not register this amount accurately, the water line is altered by the addition or substraction of water in proportion to the degree in which the meter is "fast" or "slow." Reference to Fig. 26 will show the details of construction of the cubic foot test. The large tap at the bottom is for the purpose of running the water off after using the measure, while the small lever tap at the side admits the water from the cistern. A three-way cock at the uppermost extremity permits of the measure being either placed in communication with the external air, by means of a small orifice on the right hand side of the tap, or turned so as to communicate only with the meter to be tested. The tubes at each extremity of the measure are made of stout glass, and about midway on each is pasted a strip of paper to indicate the exact measure of the cubic foot. When the instrument is being used, the bottom tap being closed, communication is made to the external air by means of the upper three-way tap. Water is then allowed to enter by the small side lever tap until it reaches the mark on the lower tube. Connection is then established to the meter to be tested by turning the three-way cock, and the water being allowed to enter the measure, drives the air through the meter at a pressure which should not exceed from a half to three-quarters of an inch. When the water has risen to the mark in the upper glass tube, the water supply is shut off and the registration of the meter noted, when correction may be made by the addition or abstraction of water for any error. A thermometer is attached to the outlet of the cubic foot test and likewise to the photometer meter, and any difference between the two has to be made a matter for correction.

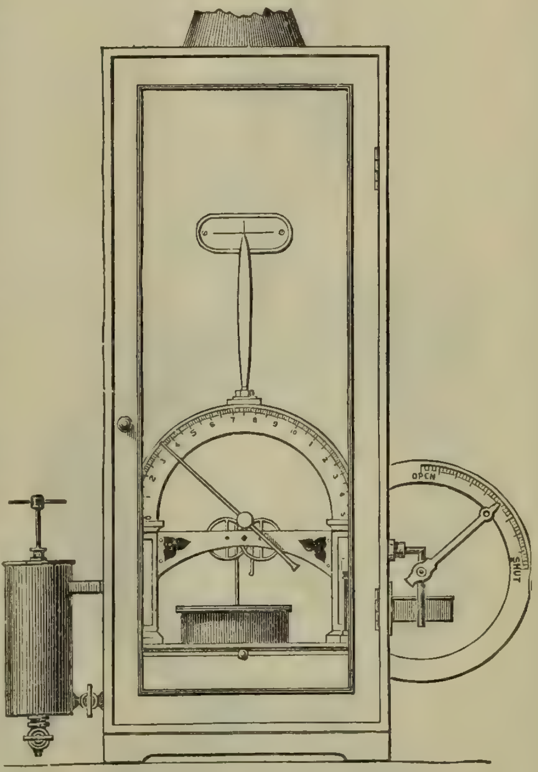
Fig. 26.



Besides the ordinary photometer as a means of estimating the value of coal gas as an illuminating agent, an apparatus termed the jet photometer is largely used especially upon the gas works. The indications of this instrument are not considered as a rule so accurate as those of the Letheby or Evans photometers, but on the other hand the jet photometer affords a speedy and continuous means of ascertaining the lighting value of gas, and is largely in use for this purpose by managers of gas works. The utility of this instrument, which is shown in Fig. 27, depends mainly on the fact that when a gas is burnt from a small orifice in such a way as to give a flame of a constant height, that the pressure required will vary with the quality of the gas. The richer the quality of the gas, the less the pressure required to maintain the flame at a given height; while, on the other hand, the poorer the quality of the gas the greater the pressure necessary. In the ordinary jet photometer the flame is maintained at a constant height of 7 inches, and the pressure required for the purpose, as indicated by a King's gauge, noted; reference to a table supplied with the instrument then shows the illuminating power of the gas in standard sperm candles. Referring to the illustration, it will be seen that the jet of gas issues from the nipple at the top of the King's gauge. The semicircular scale of the gauge is graduated in tenths and hundredths of an inch, and in order to make the instrument as delicate as possible the spindle of the index hand moves on friction wheels. The height of the flame is ascertained by a mark on the back of the box and a graduated scale on the glass door (not shown in the engraving). The quadrant and hand on the right of the instrument permit the ready adjustment of the gas supply, while the circular vessel on the left is for the purpose of regulating the height of the water line.

The latest improvement in methods of estimating the illuminating power of gas is an invention of William Sugg, in which the principle of the jet photometer is somewhat extended. In this apparatus, which is called by its inventor "The Illuminating Power Meter," the gas is burnt in a specially constructed Argand burner, the height of the flame being adjusted to exactly 3 inches. The *amount* of gas consumed in a given interval of time (one minute) is then taken, the meter dial being so graduated that its divisions represent the equivalent of the gas direct in standard sperm candles. From what has been stated when speaking of the ordinary jet photometer, it will be at once perceived that the *less* the quantity of gas which is required to maintain a flame of a given height during a known interval of time, the richer must be the quality of the gas and the higher its illuminating value.

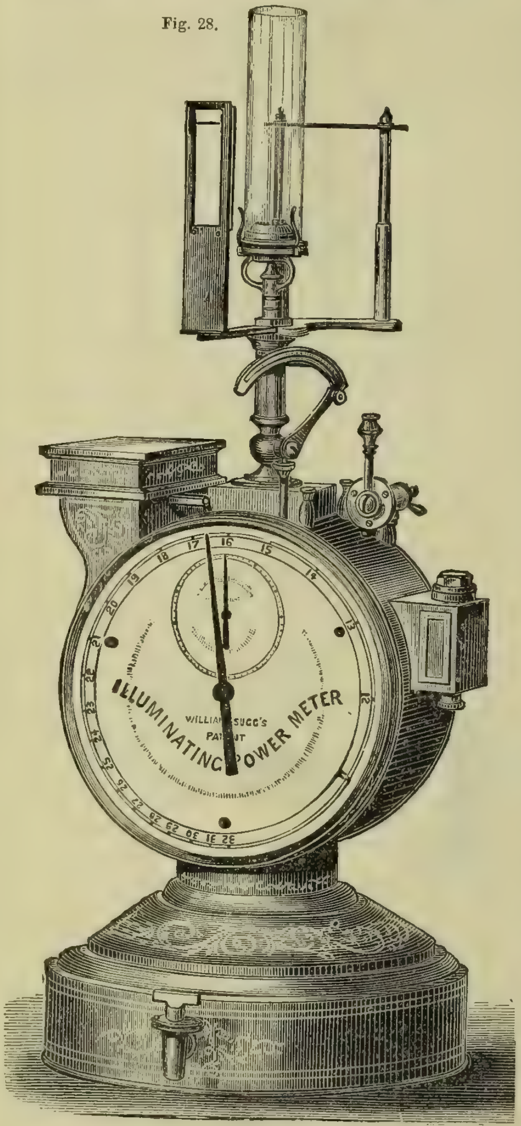
Fig. 27.



The annexed illustration, Fig. 28, shows the appearance of the instrument, and the following is a description of its construction, and the method of using it. The description is taken from the "Gas Journal:"—.

"A 'London' Argand burner, provided with a well-made cylindrical chimney, is fixed, by means of a ground swivel joint, on the top of a pillar screwed on to a hollow rectangular base, which is firmly soldered to the outer case of an experimental meter. This base has no communication with the inside of the meter-case. That part of the pillar between the top of the base and the burner forms a cock, the gas-way of which is not drilled in the usual manner, but is slotted across the plug. The sides of this gas-way being parallel to each other, it follows that, unlike those cocks fitted with round-way plugs, the cock opens when the lever is turned by regular gradations until it is full open. A quadrant, divided into forty-five equal divisions, attached to the cock, enables the operator to regulate the flow of the gas to any required rate with rapidity and precision. Above the quadrant a sighting frame is fixed, having two upright pillars, crossed by a flat bar at one end, and at the opposite end a frame fitted with blue glass. A scratch is made across the glass exactly 3 inches above the solid part of the frame. The bottom of the opening, the top of the burner, and the termination of the thick part of the back columns are all on the same level. The scratch on the glass, and the bar which crosses the back pillar, are also on the same level, and parallel to the three lower points just mentioned. By these arrangements the operator is enabled to adjust the height of the flame to the level of the scratch and the back bar.

Fig. 28.



"It may be observed, in passing, that if some points in the flame pass the line by about one-eighth of an inch, it will make but a very slight difference to the result. There will always be small points which will look like flame, but which are only heated air. A few minutes practice will suffice to enable any one, without previous knowledge of the instrument, to adjust the height of the flame.

"On the left side of the hollow base on which the pillar stands is a tube which connects this base to the outlet of a double governor. The square box on the left of the meter is this governor, which serves to maintain uniformity of pressure during the time the instrument is in use. This governor is adjusted so as to give pressure enough to make the flame tail over the chimney when the regulating-cock is full open.

"On the right of the hollow base is fixed a two-way cock, with a lever ending in a knob fixed to its plug. The cock is quarter stopped, so that when it is turned in one direction as far as the stop it is full open, and in communication with the inside of the meter, which is full of measured gas. In this position the measured gas passes through the length of the plug of the cock, and by means of a tube fixed to the end of the cock at one end, and to the inlet of the double governor at the other, it finds its way through the governor to the hollow base, and finally to the burner. While the gas is passing to the burner by this route, the measuring-drum of the meter revolves; but if the lever of the cock is turned in the opposite direction until it meets the stop, another route is opened for the passage of the gas. Now it passes directly from the inlet of the meter without passing into the measuring-drum, through the length of the plug of the cock, and out by the same tube as before to the inlet of the governor, thence to find its way to the hollow base and the burner. In this position of the lever the measuring-drum of the meter is at rest, and the gas is unmeasured. The governor having been properly adjusted, and the meter having from eight-tenths to 1 inch of pressure at its inlet, this change in the position of the lever will not influence the height of the flame.

"The index-hand is attached to the arbor of the measuring-drum, and therefore revolves with it, both making a revolution in the same time. The dial is divided into a number of divisions corresponding with the illuminating power in average parliamentary standard sperm candles, of the different qualities of gas which will give a flame of 3 inches in height. Thus, if the meter is supplied with 16 candle gas, and the flame is maintained at 3 inches, the index-hand will make one complete revolution in one minute. If the meter is supplied with 12-candle gas, and the flame maintained at the 3-inch line, the hand will make one revolution, and a part of another, arriving at the figure 12 in one minute. With 20-candle gas it will make less than a complete revolution in one minute, and arrive at 20. The instrument is provided with a very accurate and strong minute clock, with one pointed hand, which makes a complete circuit of the small dial in one minute. This dial is divided into sixty equal divisions, representing seconds.

"On the right of the cylinder which forms the outside case of the meter is the water-line gauge, fitted with back and front glasses. At the correct water-line these glasses are scratched across. On the top of the water-gauge is a large nut, which can be unscrewed when it is required to fill the meter or clean the gauge-glasses. The plug at the lower part of the gauge is for the purpose of running out the water if there is too much in the meter.

"In the base of the meter is a cock for the purpose of emptying all the water out of it, when it is requisite to do so. This meter should never be turned upside down for the purpose of emptying, or some water will get into the governor and connections, and probably cause trouble. For the purpose of filling the meter, a solution of one part of good glycerine, free from acid, in three parts of distilled water, should be used.

"The mode of putting it into operation is very simple. Having filled the meter up to the water-line scratched on the glass, connect it to the gas supply with a piece of metal tube. The inlet is a ground union joint, fixed in the centre of the back of the instrument. Turn the lever so as to make the gas pass through the measuring-drum, and let it get rid of all the air or other kind of gas in it. Light the burner, and adjust the flame to 3 inches in height. Then, when the large hand arrives at sixteen, change the position of the lever, so as to make the gas pass to the burner without going through the measuring-drum. The large hand will then stop at sixteen. Wind up the clock by means of the *remontoir* on the top of the meter just in rear of the dial ring. Start the clock by moving the slide which is on the left of the meter, close to the governor. Then, when the hand of the clock is passing any one of the divisions of the minute, change the position of the lever of the bye-pass, so as to make the gas pass through the meter. When the minute hand has made one complete revolution, stop the meter by means of the lever, in the manner before described, and read off the illuminating power. The minute clock should not be stopped either before or after the observation, unless it is desired to put the clock entirely at rest."

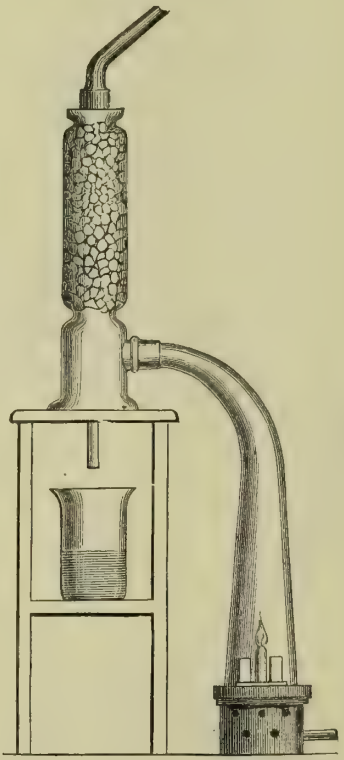
In all the previously described methods of ascertaining the illuminating power of gas, the comparison, either directly or indirectly, has been the standard sperm candle. The candle is, however, by many observers considered open to several objections as a comparative test, and there is every reason to believe that the axiom, "that the amount of light evolved is exactly proportional to the weight of sperm consumed," is not strictly true for rates of consumption differing in any large degree from the standard amount. Several attempts have been made to supersede the use of the candle by the adoption of some more reliable standard. Foremost among many suggested standards is that of a Carcel lamp burning pure sperm oil, proposed by KEATES, and the photometer readings under such conditions are certainly remarkably constant. Another proposed lamp is that of W. CROOKES, in which a mixture of pure benzol with pure alcohol is used as a source of light, the wick of the lamp being composed of fine woven platinum wire. Still more lately, VERNON HARCOURT has recommended the use of a "Standard Gas," prepared by impregnating pure hydrogen with the lighter portions of petroleum oil. By using known quantities of materials the gas is made to possess a light-giving power of 16 candles, and thus to admit of direct comparison with the gas to be tested. With gas of higher or lower quality than 16 candles, the standard gas would be proportionately modified. The substitute for standard candles has, however, not yet come into extensive use, and certainly on the score of cleanliness, portability, and facility of manipulation they are not likely to be equalled. Two other methods of estimating lighting power have been recently proposed, viz., that by the mechanical action of light on the principle of CROOKE'S radiometer, and that of Professor ADAMS and Dr. W. SIEMENS, by the alterations in electrical conductivity of selenium; experience has, however, proved that neither of these methods is trustworthy.

Testing for Impurities—Sulphuretted Hydrogen.—The usual test for sulphuretted hydrogen consists of strips of bibulous paper moistened with a solution of lead acetate. Exposure to gas containing sulphuretted hydrogen discolours the paper to a degree proportionate to the amount of impurity present. The test for sulphuretted hydrogen is generally carried on continuously, fresh strips of lead paper being used every day. Reference to the Plate of photometric apparatus will show the form of this sulphuretted hydrogen test used at the official testing stations shown at D. The strips of paper are suspended on small brass hooks, the gas entering in such a way as to impinge on the centre of each slip of paper. A bell glass cover surmounts the apparatus, the edges of the glass dipping into a narrow circular trough filled with mercury, and thus rendering the whole apparatus gas tight.

Sulphur Compounds other than Sulphuretted Hydrogen.—An apparatus, known as "The Referee's Sulphur Test," is used for the purpose of estimating the sulphur compounds existing in the gas in other forms than sulphuretted hydrogen. This apparatus is illustrated in Fig. 29.

Its action depends on the fact that when gas containing sulphur is submitted to complete combustion in presence of the vapour of ammonia, the whole of the sulphur assumes the form of sulphuric acid, which then unites with the ammonia to form ammonium sulphate. In the referee's test, the gas is consumed in a small Bunsen burner at the rate of about half a cubic foot per hour. The space round the burner is packed with ordinary ammonium carbonate; and the products of combustion, together with the ammonia evolved continuously from the ammonium carbonate, are conveyed by the glass trumpet tube into the vertical vessel called the "sulphur cylinder." The latter is packed with glass beads, and is provided at the top with an outlet tube several feet long. At the base of the sulphur cylinder is fitted a small glass tube, which projects through the top of the wooden stand used for supporting the apparatus, a beaker glass being placed beneath to receive the liquid products of combustion. During the combustion of the gas the hydrogen is converted into aqueous vapour and the sulphur into sulphuric acid, and these products are condensed in passing over the large surface presented by the glass beads, which are kept continually moist by the liquid which is produced by the further and complete condensation effected by the long glass exit tube. The condensed products find their way into the glass beaker placed for their reception. The sulphur apparatus is generally used with a "10-foot stop meter," which after passing 10 cubic feet of gas shuts off the gas supply by an automatic mechanical action. The amount of gas consumed is thus always a known quantity. At the expiration of the 10-foot consumption, the liquid which has collected in the beaker, and which as a rule amounts to from 5 to 10 ozs., is transferred to a measuring glass; and the whole of the sulphur apparatus being then thoroughly washed out with distilled water, the washings are added to the contents of the measure and the whole made up to a convenient quantity by the addition of distilled water. The contents of the vessel having been well mixed, one half of the total quantity may be then taken for analysis. For this purpose the liquid is transferred to a beaker glass, an excess of hydrochloric acid added, and the whole boiled. While in a boiling condition a slight excess of a solution of barium chloride is added, which throws down the whole of the sulphuric acid present in the form of insoluble barium sulphate. The beaker is then removed from the source of heat, and the contents allowed to stand for some hours in order to allow the precipitated barium sulphate to settle. The comparatively clear liquid is then filtered, and the precipitate itself eventually brought on the filter and washed with boiling distilled water until the filtrate remains clear on the addition of silver nitrate solution. The filter and its contents are then dried, ignited in a platinum crucible, and weighed.

Fig. 29.



The amount of sulphur present can then be found from the combining weights of sulphur and barium sulphate as follows:—233 (equivalent weight of barium sulphate) is to 32 (equivalent weight of sulphur), as the weight of barium sulphate obtained is to the amount of sulphur sought; or barium contains 13·7 per cent. of its weight of sulphur. As half only of the products of combustion were taken for analysis, the result obtained must be multiplied by two to get the total quantity from 10 feet, which, multiplied by ten, will give the amount of sulphur per 100 cubic feet.

A simpler rule in practice is to multiply the barium sulphate obtained from half the products of combustion by eleven and divide by four; the result is sulphur per 100 cubic feet. Whichever rule is used in practice, the quantity of sulphur eventually obtained must be divided by the tabular number corresponding to temperature and pressure in order to arrive at the correct amount.

In starting the sulphur apparatus fresh ammonium carbonate is used each time, and care should always be taken that the indiarubber joints at the junction of the trumpet tube with the sulphur cylinder, and at the union of the latter vessel with the outlet tube, fit tightly and are in good condition.

Recently another form of sulphur test has been introduced, and is now in use in many gas works, where its rapidity of action and facility of manipulation are of great value. The apparatus referred to is VERNON HARCOURT'S sulphur test, and the principle of its action is founded on the facility with which carbon disulphide can be converted into sulphuretted hydrogen by the agency of heat.

The apparatus consists of a flask, which is filled with pebbles and heated by a ring burner, the whole arrangement being surrounded by a fireclay cylinder in order to retain the heat. Two small glass cylinders are provided, one of which contains a liquid of a pale brown colour, which is used as the standard of comparison. During testing, the other cylinder is filled with a prepared lead solution, and placed next to the standard colour. Gas is now drawn through the apparatus, passing in its course through the lead solution by means of an aspirator, the water coming from the aspirator being received into a graduated jar. It is obvious that the quantity of water received by the graduated jar is a measure of the amount of gas passed through the apparatus. During the passage of the gas through the lead solution, the liquid assumes a brown tint, due to the production of lead sulphide; and when the intensity of the colour equals that of the comparison liquid, the aspirator is stopped. The amount of liquid in the graduated cylinder is then noted, and reference to a prepared table shows the amount of sulphur present in the gas. It has been found in using this apparatus that it indicates an amount of sulphur short of the total amount present by about 7 grains per 100 cubic feet. This proves either that the conversion of the carbon disulphide into sulphuretted hydrogen in the apparatus is not complete, a fixed quantity of the former always escaping decomposition, or that this residual 7 grains of sulphur exists in some other form than carbon disulphide. The latter view is probably the correct one.

WILLS has recently suggested an improvement in VERNON HARCOURT'S original apparatus. It is found in using the test that after a time its action becomes slower, and that unless certain precautions are taken, the apparatus eventually becomes altogether inefficient. The effect appeared to be due to a superficial film of carbon, with which the surface of the pebbles became covered; and in order to render the test again efficient, it was necessary to pass a current of air through the apparatus in order to cleanse the surface of the pebbles. WILLS uses platinum as a substitute for the pebbles, and the improvement is found to answer exceedingly well, the decomposition of the carbon disulphide taking place at a comparatively low temperature. In practice the platinum surface is economically secured by soaking fragments of pumice in a solution of platinic chloride, and subsequently igniting them, when the decomposition of the platinum salt gives sufficient metallic platinum to produce the desired effect. The fragments of platinized pumice are placed in a glass flask, into which the gas is conducted, and the flask is placed in an ordinary air bath heated by a gas jet, a sufficient temperature being thus obtained to completely decompose the carbon disulphide present. The platinized surface always remains efficient, and the apparatus is thus continuous in its action.

Ammonia.—The qualitative test for ammonia is generally moistened turmeric paper or red litmus paper, the former becoming brown and the latter blue under the influence of gas containing ammonia. The quantitative test is usually made in connection with the sulphur apparatus, the 10-foot stop-meter being used for both the sulphur and ammonia. In testing for the *amount* of ammonia present in gas, the gas is passed through a tube filled with glass beads and charged with a measured quantity of standard sulphuric acid. Any ammonia present is thus absorbed during the passage of the gas over the wetted beads, an equivalent quantity of the acid becoming neutralized. By the use of a standard solution of ammonia, the amount of acid which remains unneutralized at the end of the experiment is then determined by titration, and the quantity of ammonia present thus estimated. In practice the strengths of the standard acid and ammonia are so proportioned that the quantity of ammonia present in the gas may be found by a simple rule, and all undue trouble of calculation thus avoided. The standard acid is made of such a strength that 25 septems* will exactly neutralize 1 grain of ammonia, while standard ammonia contains 1 grain of the alkali in 100 septems of the solution. In making a test the ammonia tube is charged with 50 septems of standard acid, and connected with the 10-foot stop-meter in such a way that the gas passes through the tube prior to its entering the meter. At the termination of the experiment, 10 cubic feet of gas having passed, the ammonia tube is disconnected, and its liquid contents allowed to drain into a graduated jar, distilled water being finally allowed to flow through the tube to remove all traces of acid. The liquid in the jar is then made up to a convenient quantity with distilled water, and half of the amount transferred to a beaker. A little hæmatine tincture is then added, and the standard ammonia run in from a graduated 100-septem burette, until the yellow colour of the liquid has changed to a crimson, proving that all the free acid present has become neutralized. Should the gas have contained no ammonia the whole of the 100 septems of standard alkali will be required to effect the neutralization; supposing, however, that ammonia is present, less alkali will be subsequently required in proportion. Let it be assumed, for instance, that 95 septems only have been required to effect neutralization, then, as every septem of the standard solution contains 0·01 grain of ammonia, it proves that the acid has been neutralized to an extent equal to $5 \times 0·01 = ·05$ grain of ammonia; and as only half the amount of the total liquid has been taken for experiment, this result must be doubled, which gives 0·1 grain from 10 feet of gas, or 1 grain of ammonia per 100 cubic feet. In practice the simple rule for calculating the amount present, presuming the experiment to have been conducted in the way indicated, is as follows:—Multiply the number of septems of ammonia solution remaining in the burette by 0·2, and the result gives the grains of ammonia present per 100 cubic feet of gas.

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* The septem is the measure of 7 grains of water, and is the ten-thousandth part of an imperial gallon.

Residual Products.—In the present economy of gas manufacture the value of the substances produced at the same time as the gas is a most important matter. From being originally an absolute source of nuisance, many of these residual products have now become of considerable commercial value. The so-called "gas or ammoniacal liquor" is the source of most of the ammonia salts to be met with in commerce; while the tar has acquired value for the production of the aniline colours, and also as a source of carbolic acid, which is largely in use at the present time for disinfecting purposes.

The principal use of the ammoniacal liquor is in the preparation of crude ammonium sulphate, which is employed for agricultural purposes as a manure; it is also to a minor extent the source of the purer ammonia salts. The treatment of the liquor for this purpose constitutes a distinct and remunerative branch of manufacture. The actual process employed has been already noticed in the article on AMMONIA in the present work, to which reference should be made for further details. The commercial value of "gas liquor" is determined by the number of ounces of strong monohydrated sulphuric acid (H_2SO_4) required for the neutralization of 1 gallon, the result being expressed as so many "ounce" liquor. This method of valuation is defective in taking no cognizance of the ammonia present in a combined form not decomposable by dilute acid. This amount is variable, but is always a very appreciable quantity. Distillation of the liquor with an alkali, and the condensation and estimation of the ammonia liberated, is the only trustworthy method, and this mode is now being adopted in place of the older system. Coal tar is treated in order to obtain a variety of substances, all of which have a commercial value (see COAL TAR DISTILLATION). Of the other bye products of a gas works, coke always commands a ready sale, while for breeze the demand is more variable, and the value conconsiderably less. Spent oxide is not at present a source of revenue to gas companies, but the terms upon which it is supplied and removed are a matter of consideration. The cause of these favourable terms is understood when it is considered that foul oxide will often contain from 40 to 55 per cent. of free sulphur, a very appreciable quantity of impure ammonia salts, and some Prussian blue, products which, if extracted, are readily saleable. Gas lime, *i.e.*, foul lime from the purifiers, is not only in many cases absolutely unsaleable, but is frequently a source of considerable nuisance to the companies of London and other large towns. In the country the spent lime is in demand among the neighbouring farmers for manurial purposes.

The aggregate value of the whole of the residual products of a gas manufactory at the present time may be taken at about one half the cost of the original coal. In order better to illustrate this, and also to help the reader to form some idea of the individual value of each bye product, we take as an example a condensed statement from the published accounts of the Commercial Gas Company for the half year ending June 30, 1875. The total amount of coal carbonized amounted to 48,380 tons, of which 43,929 tons were common coal, and 4451 tons cannel; this yielded residual products as follows:—

Coke (chaldrons of 36 bushels),	44,838
Breeze, " "	5,425
Tar (gallons),	435,182
Ammoniacal liquor (butts of 108 gallons),	8,653

Of these amounts the quantities sold and values received were as follows:—

	Sold.	Value received.		
		£	S.	D.
Coke (chaldrons),	34,261	15,240	13	5
Breeze, "	* 6,024	18	18	7
Tar (gallons),	*441,182	3,914	7	3
Ammoniacal liquor,	8,468	2,838	12	9
		22,012	12	0

* The slight excess over the quantity made was probably due to a small amount being in stock at the commencement of the half year.

The cost of the coal was about £46,900, including dues, &c., and the realized value of the residuals sold £22,012 12*s.*, after deducting cost of labour and cartage for the breeze and coke; as, however, the quantity of coke sold was less than the quantity obtained by about one-fifth (this amount having been used in the retort furnaces), it will be seen that the total value of the residual products in this case was considerably more than one-half the cost of the original coal. From an analysis of the aggregate figures the realizable value of each residual expressed in minor terms is as follows:—

	S.	D.
Coke, per chaldron,	8	10¾
Breeze, "	0	0¼
Tar, per gallon,	0	2
Ammoniacal liquor, per butt,	6	8¼

There is little doubt that the large gas companies will turn their attention more and more in the future to the proper valuation, as well as the more profitable utilization, of these residual products. A small increase of plant would enable a gas company to turn its own ammoniacal liquor into the more saleable and convenient form of ammonia salts, the doing of which would undoubtedly be profitable.

Improvements in this direction will in the long run be to the advantage of the gas company, and also to the gas consumer.

INDEX.

VOL. I.

A

Acet-toluide, 209.
Acetanilide, 209.
Acetate, ammonium, 42.
" ferrous, 45.
" manganese, 51.
" neutral, 47.
" of amyl, 846.
" of copper, 42.
" of lead, brown, 47.
" of lead, white, 48.
" of lime, 27, 49.
" of lime, Völckel's process for obtaining, 29.
" of methyl, 58.
" of soda, 51.
" of soda, use of, as a food preservative, 52.
" of the protoxide of tin, 53.
" zinc, 54.
Acetates, ferric, 46.
" ferrous, 45.
" lead, 47.
" metallic, 54.
" potassium, 53.
ACETIC ACID—1-59.
" ancient knowledge of, 1.
" and acetates from distillation of wood, Pauer's process, 26.
" Condy's process for the purification of, 31.
" first obtained as a pure hydrate, 1.
" formation of, synthetically, 5.
" from oxidation of alcohol, 3.
" from sea-weed, 15.
" glacial, 1.
" Oudemanns' table, 35.
" power of, in cases of poisoning, 3.
" pure, from brandy vinegar, 34.
" purification by hydrocarbon vapours, 32.
" rectification of, 30.
" specific gravity of, 2.
" testing, 35.
" use of in dyeing and calico printing, 39.
Acetic ether, 57.
" properties of, 57.
Aceto-arsenite of copper, 260.
Acetometer, Otto's, 36.
Acetone, 58.
Acetum saturni, 49.
Adjective colours, 629.
Adulterations of spirituous liquors, 152.
Air, dust and germ laden, 603.
Air, filtration of, 607.
ALCOHOL—59-153.
Alcohol, absolute, 60.
" boiling point of, 144.
" by synthesis, 66.
" considered in a strict chemical sense, 59.
" decomposition of, 64.
" detection of copper and lead in, 153.
" discovery of, 60.
" Gay Lussac's tables for dilution of, 150–152.
" grinding malt and grain, 69.
" its aqueous solution, 63.
" its properties, 62.
" lamp, without flame, 65.
" malting, 68.
" mashing, temperature of, 71.
" method of discovering its origin, 110.
" not known to the ancients, 59.
" use as a solvent, 64.
" vapour, 64.

Alcoholate, chloral, 470.
Alcoholic adulterations, and detection, 152.
" fermentation, 75.
" liquors, 66.
Alcoholometer, Field's, 144.
" Sikes', 140.
" Silbermann's, 148.
Alcoholometric tables, Fownes's, 147.
" " Gay-Lussac's, 131–139.
" " Lowitz', 139.
" " Sikes', 141, 142.
" " Tralles', 126–131.
" " Ure's, 143.
Alcoholometry, 125.
Aldehyde, formation of, 13.
Ale, brewing pale, 327.
" pale, 327.
Ales, Scotch, 328.
Alizarin, 512.
" apparatus for the manufacture of, 515.
" dyes, 629, 654.
" from madder, extraction of, 630.
" manufacture, 514.
" preparation of, 514.
" preparation of artificial, 630.
" purification of, 519.
Alkalies in cement, 463.
Alloys, aluminium, 180.
" of copper and tin, 582.
" of copper and zinc, 575.
" of iron and copper, 573.
Almond cake, 109.
ALUM—153–180.
Alum, ammonia, 171.
" ammonium, 176.
" boiling the crude lie, 163.
" bye-products, 170.
" chemistry of, 175.
" clarified liquor, 162.
" concentrated liquor, 162.
" crystallization of, 168.
" earth, 158.
" evaporation of, 164.
" feather, 159.
" from Rodonda phosphates, 174.
" " China-clay, 172.
" " clay, 171.
" " cryolite or Greenland spar,
" " 173.
" " felspar, 172.
" " pipe-clay, 172.
" " rocks containing alumina, 171.
" impurities, 175.
" lixiviation, 161.
" manufacture from alum stone, 155.
" " from alum ore, 156.
" " from alum shale, 156.
" " historical sketch of, 154.
" " improvement in, 174.
" mother liquor, 162.
" ores, Campsie, 157.
" powder, 170.
" precipitation, 165.
" preparation of the powder, 165.
" produce, 175.
" raw liquor, 166.
" roasting in heaps, 159.
" roching, 168.
" salt-mothers, 162.
" shale, analysis of, 156.
" " composition of, 157.
" " manufacture from, 156.
" " preparation of the, 159.
" Spence's process, 171.
" tun-liquor, 162.
" uses of, 178.
" washing, 162, 167.
Alumina, 178.
" compounds, 179.

Alumina, crystallized, 178.
" in cement, 463.
" preparation of, 178.
" production of alum from rocks containing, 171.
" sulphate of, 177.
Aluminiferous minerals treated with sulphuric acid, 171.
Aluminium, 179.
" boride, 405.
" oxide, 178.
" properties of, 180.
" smelting, 180.
" sulphate, 177.
" sulphate, composition of natural, 159.
" triacetate, 39.
Amaranth dye, 774.
" spirit, 754.
AMMONIA—180-204.
Ammonia, agricultural value of, 201.
" alum, 171.
" boiling point, 187.
" carbonate of, 200.
" decomposition of, 182.
" discovery of, 180.
" distilling apparatus, 185.
" estimation of, 201.
" estimation by Nessler's solution, 203.
" from distillation of bones, 189.
" from gas liquor, 184.
" from guano, 184.
" from peat, 199.
" gaseous, 180.
" in bread, 430.
" in gas, testing for, 1037.
" its uses, 201.
" liquid, 182.
" manufacture of, 183.
" preparation of, 181.
" salts of, from guano, 198.
" sesquicarbonate of, 199.
" strength of, 187.
" sulphate of, 196.
" uses of, 182.
Ammoniacal cochineal dye, 631, 653.
" salts, 183.
Ammonium acid acetate, diacetate, 42.
" acetate, 42.
" alum, 176.
" arsenate of, 264.
" chloride of, 188.
" chloride, preparation of, 192.
" chloride, sublimation of, 195.
" platino-chloride, estimation of ammonia as, 202.
" sulphate, manufacture from gas liquor, 197.
" sulphate, 196.
" sulphate and chloride of, 198.
Amyl, acetate of, 846.
" butyrate, 847.
" valerate of, 848.
Anæsthetics, 204.
Anæsthesia, local, 204.
Analysis of alum crude liquor, 163.
Angelica root, 109.
Anhydrous boric acid, 406.
ANILINE AND ANILINE DYES—204–242.
Aniline, chemical properties of, 206.
" dyes, 217, 625, 639.
" dyes, manufacture of, 222.
" dyes, general history of the, 217.
" dimethyl, 210.
" dimethyl, manufacture of, 216.
" discovery of, 205.
" ethyl, 211.
" from amidobenzoic acids, 206.
" formed from benzene, 205.

Aniline from phenol, 205.
" homologues, 205.
" methyl, manufacture of, 216.
" oils, heavy, 214.
" oils, light, 214.
" oils, manufacture of, 211.
" oil, yield of rosaniline from, 227.
" production of, 205.
" spirit, 755.
" substituted, 209.
" tailings, 214.
Animal charcoal, 393.
Annotta dyes, 625, 653, 751.
Anthracene, 508.
" alcohol test, 510.
" arrangement for distilling, 504.
" carbon disulphide test, 511.
" discovery of, 509.
" manufacture of, 510.
" refining, 512.
Anthraquinone, 513.
" and its derivatives, 512.
Antimonial copper, 242.
" ores, dry assay of, 251.
Antimonic sulphide, 248.
Antimonious oxide, 249.
" sulphide, 247.
ANTIMONY—242-252.
Antimony, amorphous trisulphide of, 247.
" butter of, 249.
" distribution of, 242.
" its uses in the arts, 246.
" livers of, 249.
" manufacture of, 243.
" quantitative estimation of, by analysis, 250.
" sources of, 242.
" trichloride of, 249.
" trioxide of, 249.
" trisulphide of, 247, 634.
Appolt's coke oven, 962.
Aqua vitæ or usquebaugh, 67.
Archil, 624.
" dyes, 741.
Argand burners, 1026.
Amyl, valerate of, 848.
Aromatic vinegar, 34.
Arrack of Batavia, 113.
" recipes for making, 123.
" spirit, 122.
Arsenate of ammonium, 264.
" of lead, 264.
" of magnesium, 264.
ARSENIC—252-266.
Arsenic acid, 261.
" associated with antimony, 251.
" Bloxam's test, 263.
" Brunton's calciner, 255.
" calcining in kilns, 256.
" chambers, 256.
" detection of, 261.
" detection of, by bichromate of potassium, 264.
" detection of, by Marsh's test, 262.
" dyes, 731.
" glass, manufacture of white, 258.
" manufacture of flour of, 253.
" manufacture of white, 253.
" refining or resublimation, 257.
" Reinsch's test, 262.
" roasting in a muffle furnace, 256.
" roasting in a reverberatory furnace, 254.
" roasting or calcination, 254.
" quantitative estimation, 263.
" separation from other metals, 265.
" sources of, 252.
" trihydride, 261.
" Ure's modification of Marsh's test, 262.
Arsenious acid, 253.
Arsenite of copper, 260.
" potassium, 260.
Arsenites, 260.
Artificial disinfectants, 612.
" fuel, 969.
" substantive colours, 625.
Asphalt, 356.
" artificial, 362.
" concrete, 359.
" mixtures for artificial, 364.
" uses of, 359.
" Val-de-Travers, 362.
Asphalting, 360.
Assaying copper, dry way, 570.
" " wet way, 571.
Atacamite, 543.
Atmospheric air, 986.
Aurin dyes, 628.
Azelaine, 626.
Azobenzene or Azobenzide, 209.
Azotoluene, 209.
Azulin, 628.
Azuline, preparation of, 235.
Azurine, preparation of, 235.
Azurite, 543.

B

Baking apparatus, 419.
" oven, 423.
Balm of Gilead, 267.
BALSAMS—266-273.
Balsam, Black Peru, 272.
" Canada, 266.
" Copaiba, 266.
" dry Peru, 273.
" Mecca, 267.
" of Peru, 269.
" of Peru, black, analysis of, 273.
" of Peru, historical account of, 269.
" of Peru, white, 271.
" of Tolu, 268.
" Paracopaiba, 267.
" Storax, 267.
Bancroft's scarlet spirit, 754.
Barley, 409.
" as malt, composition of, 282.
" composition of the ash of, 282.
" composition of raw and malted, 281.
Basic nitrate of bismuth, 354.
Batteries, galvanic, 800.
" thermo electric, 807.
" " management of, 815.
Bavarian beer, 330.
BEER—273-341.
Beer, adulteration of, 333.
" analysis of, 333.
" ash of, 340.
" Bavarian, 330.
" boiling coppers for, 304.
" boiling the worts, 301.
" boiling the worts by steam, 305.
" brewing, 287.
" cask washing, 326.
" cleansing, 319.
" composition of various kinds of, 341.
" description of Plate, 327.
" detection of spurious bitters in, 338.
" faro, 333.
" historical account of, 273.
" inorganic adulterations in, 336.
" isinglass used for fining, 330.
" kiln drying of malt, 278.
" Lambick, 333.
" malt-kiln, construction of a, 278.
" malt and malting, 274.
" malt drying, 279.
" malt flooring, 277.
" malt steeping, 275.
" malt testing, 280.
" mash-tun for, 291.
" method of ascertaining amount of alcohol, 334.
" saccharometer, 298.
" selection of barley, 274.
" the couch, 276.
Beetroot, rum from, 118.
Bell metal, 597.
Bengal cutch, 745.
Benzaldine, 351.
Benzene, 342.
" boiling point, 343.
" derivatives, 347.
" first discovered by Faraday, 342.
" how obtainable, 342.
" isomerides, various, 344.
" tetramethyl, 344.
Benzoate of ethyl, 847.
Benzoic aldehyde, 351.
" ether, 847.
BENZOL—341-351.
Benzol, distillation of, 345.
" distillation, figure of still, 346.
" Kekulé's notation, 342.
" manufacture of, 344.
" symbols, 341.
Benzoyl hydride, manufacture of, 351.
Benzyl-rosaniline, 627.
Béton, 466.
Biborate of soda, 400.
Biscuit-making, mode of working, 427.
BISMUTH—352-355.
Bismuth, detection and estimation of, 355.
" furnaces, figures of, 352.
" nitrates, 354.
" ores, 352.
" oxides, 354.
" oxychloride of, 354.
" preparation of, 352.
" properties of, 353.
" refining, 353.
Bismuth, uses in the arts, 353.
Bitter almonds, oil of, 351.
BITUMEN—356-364.
Bitumen of Cuba, 358.
" solid, 357.
" table showing composition of, 358.
Black dyes, 221, 639, 641, 654, 760, 764, 769, 772, 774, 778.
BLEACHING—364-391.
Bleaching, antiquity of, 364.
" application of lime to cloth, 667.
" amount of lime to be used, 667.
" boiling with lime, 668.
" boiling with soda ash and rosin, 669.
" Claussen's process, 381.
" continuous process, 380, 386.
" cotton, 365.
" final washing out of sours, 670.
" first washing, 667.
" flax, Buchanan's retting machine, 374.
" for dyeing, 666.
" high and low pressure, 670.
" linen, 385.
" linen, Irish methods, 385.
" linen, Old Bielefield method, 385.
" linen, Bouchard's continuous process, 386.
" liquor, 753.
" of wool, 387.
" of wool by ammonia, 388.
" of wool by fusel oil, 388.
" powder process, 237.
" powder, manufacture of, 476.
" powder, 375.
" liquor, treating with, 376.
" recipe to prepare a sour, 753.
" rot steep, 666.
" scouring machines, 367.
" souring after chloride of lime, 669, 670.
" spirits, 753.
" stearic acid for candles, 450.
" steeping, 666.
" straw, 391.
" the Grean process, 380
" the American process, 380.
" treatment with chloride of lime, 670.
" washing after liming, 668.
" washing out of soda ash, 670.
" wax, 453.
" wetting out, 666.
" with chlorine gas, 375.
" working of kiers, 670.
Blister copper, refining, 582.
Blue dyes, 218, 219, 231, 232, 233, 234, 235, 530, 627, 634, 640, 653, 737, 761, 766, 772, 776, 778.
Blue stone, 600.
" verdigris, 43.
" vitriol, 600.
Boiling coppers for beer, 304.
BONE—391-393.
Bone ash, 392.
" boiling out the grease, 392.
" cartilage, converting into glue, 392.
" charcoal, ammonium from manufacture of, 189.
" distillation, furnace for, 189.
" glue, 392.
" glue, drying, 392.
" treating with hydrochloric acid, 392.
BONE BLACK—393-397.
Bone black, properties of, 393.
" preparation of, 394.
" revivification of, 395.
" substitutes for, 397.
BORACIC ACID—397-400.
BORAX—400-405.
Borax, adulterations of, 404.
" analysis of, 404.
" anhydrous, 403.
" calcined, 400.
" fused, 404.
" manufacture of, 401.
" native, 401.
" octahedral, 403.
" preparation of, 403.
" refining of, 402.
Boric acid, 397.
" impurities of, 400.
" preparation of, 398.
Boric anhydride, 406.
" oxide, 406.
Boride of aluminium, 405.
BORON—405-406.
Boron, adamantine, 406.
" amorphous, 405.
" discovery of, 405.
" graphitoidal, 405.

Boron, oxide of, 406.
Bottom fermentation of beer, 331.
Bournonite, 544.
Brandy, 110.
" British, 112.
" cherry, 112.
" eau de vie de marcs, 111.
" raspberry, 112.
Brass, 574.
" furnaces, 577.
" green lacquering of, 580.
" high-coloured lacquering of, 580.
" historical account of, 574.
" how made, 574.
" lacquering of, 580.
" manufacture of, 576.
" pale lacquering of, 580.
" see Copper Alloys.
" volumetric method of assaying, 597.
Brazil wood, 631, 653, 743.
BREAD—406–430.
Bread, adulterations of, 428.
" adulteration with sulphate of copper, 430.
" adulteration with sesquicarbonate of ammonium, 430.
" alum adulteration, 428.
" biscuit making, 427.
" Clayton's machine for kneading dough, 421.
" fermentation, 418.
" French ovens, 424.
" how to detect alum in, 429.
" ingredients of, 417.
" kneading, 419.
" making, 417.
" patent yeast, 421.
" the oven, 422.
" unfermented, 425.
" unfermented, Dauglish's process, 427.
Breckon and Dixon's coke oven, 965.
Brewing beer, 287.
" pale ale, 327.
" water for, 283.
British brandy, 112.
BROMINE—430–432.
Bromine, its uses, 432.
" sources of, 431.
" method of preparation, 432.
Bromized sodium chloride, 203.
Bronze, 582.
" casting, 585.
" chilled, 589.
" dyes, 772.
" furnaces, 584.
" phosphor, 591.
" phosphor, for guns, 596.
" silicate of, 531.
" volumetric method of assaying, 597.
Bronzing, 580.
" black, 580.
Brown dyes, 222, 241, 627, 640, 745, 760, 763, 767, 768, 769, 772, 773, 774, 775, 779.
Bucking cotton, 368.
" kiers, 370.
" with caustic soda, 377.
Building, cement for, 457.
Butyrate of ethel, 847.

C

Cadmium, see Paints and Pigments.
Calamus root, 109.
Calcination of bones, 394.
Calciner, Oxland and Hocking's patent, 255.
Calcium diacetate, 49.
Calendering cotton, 379.
Calico printing, 635. See Dyeing.
" ageing, 693.
" ageing machines, 694.
" application of the design to the calico, 673.
" Bibanow's tables for detecting different organic colours on tissues, 657–661.
" blocking, 673.
" boiling the colours, 678.
" chemical, 643.
" clearing of whites, 707.
" colour mixing, 678.
" colours fixed by albumen, 644.
" cylinder machines, 675.
" delaines, 652, 720.
" delaines, colours used for, 720.
" discharge style, 643.
" doctors, 677.
" dunging and fixing, 695.
" dye becks, 698.
" dyeing apparatus, 698.
" engraving, 677.
Calico printing, finishing, 708.
" fitting of patterns, 678.
" fixing, 697.
" gas singeing, 664.
" general remarks upon singeing, 665.
" history of, 662.
" lapping, 676.
" madder dyeing, 700.
" madder styles, 701.
" mandrills and rollers, 676.
" marking of the grey calico, 663.
" mordanting, 688.
" receipts, 711.
" resist style, 642.
" see Dyeing.
" shearing, 672.
" silks, colours used for, 721.
" silk stuffs and challis, 721.
" singeing, 663.
" singeing by flame and plate combined, 665.
" soaping becks, 703.
" sewing of pieces for bleaching, 663.
" steam, 638.
" steam colours, 686.
" steam green, 640.
" steaming processes, 686.
" straining the colours, 679.
" testing of colours, 652.
" the blanket, 676.
" thickenings, 635.
" thickening matters for colouring, 689.
" topical steam colours, 638.
" washing after dunging, 697.
" washing after souring, 669.
" washing the blankets, 676.
" winding-on for printing, 672.
" wool, 652.
" woollen stuffs, 719.
Campeachy wood, 631.
Campsie alum ores, 157.
Canada balsam, 266.
CANDLE—432-455.
Candle, adaptation of wax for, 453.
" form of moulds, 448.
" lard for making, 432.
" machines for dipping, 446.
" making, preparing stearic acid for, 435.
" making, value of paraffin for, 452.
" making, wax bleaching for, 453.
" moulding machines, 449.
" moulds, 447.
" paraffin, 451.
" polishing machines, 450.
" tallow for making, 432.
" wax, 452.
" wax, manufacture of, 454.
" wax, coloured, 454.
" wicks, 442.
" wicks used for wax, 454.
Cannons, casting, 588.
Caoutchouc, see India rubber.
Capaiva balsam, 266.
Caracura, 632.
Carbolic acid as a disinfectant, 613.
" modes of using, 616.
Carbon, bone black, 393.
" heating power of, 897.
Carbonate of ammonia, 200.
Carbonic acid, 987.
" oxide, 987.
" oxide, heating power of, 897.
Carbonizer Schwartz', 17.
Carbonizing charcoal, 915.
" furnace, Reichenbach's, 18.
" retorts, English, 19.
" wood, 17.
Carburetted hydrogen, 989.
Cardamom seed, 109.
Carmine, 539.
" Alyon and Langlois' method, 539.
" French method, 539.
" Madam Cenette's method, 539.
" old German process, 539.
" preparation of, 539.
" see Cochineal.
Carmin-lake, 540.
Carminic acid, 535.
Carnauba wax, 452.
Carrot spirit, 124.
Cask-lowering machine, 325.
Cask-raising apparatus, 325.
Cassia, 109.
Catechu dyes, 633, 745, 751, 760.
CEMENT—455-468.
Cement, alkalies in, 463.
Cement, alumina in, 463.
" analysis of hydraulic, 461.
" clays in, 463.
" constituents, 463.
" decorator's, 467.
" diamond, 456.
" hydraulic, 460.
" Keene's, 467.
" lime, 457.
" magnesia in, 463.
" Martin's, 467.
" miscellaneous, 456.
" mortar, 459.
" Parian, 467.
" Parker's, 464.
" preparation used by Turkish jewellers, 456.
" resinous, 455.
" Roman, 461, 464.
" Roman, composition of, 465.
" Roman, manufacture of, 465.
" Roman, kilns used for, 465.
" Varley's, 456.
Cerise dyes, 775.
Chalcophyllite, 544.
Chalcotrichite, 542.
Chamois dyes, 775.
Charcoal, 914.
" a means of removing disagreeable tastes in alcohol, 106.
" ammonia from manufacture of bone, 189.
" animal, 393.
" as a disinfectant, 617.
" burning on the continent, 918.
" burning in kilns, 920.
" carbonizing, 915.
" conducting power of, 924.
" from distillation of wood, 21.
" quality of, 923.
Chemical reactions of acetic acid, 5.
" reactions of alcohol, 65.
" steam colours, 639.
Chessylite, 543.
Cherry brandy, 112.
China clay, alum from, 172.
China wax, 452.
Chinese or Japanese galls, 633.
Chica dyes, 632, 745.
Chloral, 468.
" alcoholate, 470.
" hydrate, 470.
" hydrate, valuation of, 471.
" manufacture of, 470.
" preparation of, 468.
" properties of, 469.
Chloraniline, 211.
Chloranthracene, 516.
Chloric acid, 475.
Chloride of ammonium, 188.
" ethyl, 845.
" iron, 735.
" lime, 478.
" lime, analysis of, 479.
" methyl, 845.
" zinc as a disinfectant, 617.
CHLORINE—474–492.
Chlorine as a disinfectant, 617.
" compounds, 475.
" Deacon's process, 486.
" Deacon's decomposing towers, 487.
" gas, bleaching with, 375.
" manufacture of, 477.
" manufacture of bleaching powder, 476.
" methods of testing, 484.
" properties of, 475, 988.
" regeneration of the manganese, 480.
" sources of, 474.
" stills, 477.
" testing manganese mud, 485.
" theory of Deacon's process, 488.
" Weldon's process; 481, 486.
" Weldon's still, 483.
" gas, specific gravity of, 474.
Chlorobenzene, 349.
Chloroform, 468, 471.
" adulterations of, 473.
" discovery of, 471.
" manufacture of, 472
" properties of, 471.
Chlorometry, 489.
Gay-Lussac's method, 489.
" Penot's method, 490.
Chlorous acid, 475.
Chocolate dyes, 760.
Chrome, aceto-nitrate of, 756.
Chromic arsenite, 634.
" oxide, 633.
Chromium, 731.
Chrysaniline, 218, 627.

Chrysocolla, 543.
Chrysotoluidine, manufacture of, 228.
  " red, 218.
CITRIC ACID—492–497.
Citric acid, adulteration, 497.
  " decompositions of, 493.
  " from lemon juice, 494.
  " its uses, 497.
  " manufacture of, 494.
  " Pontifex's vacuum pan, 496.
  " properties of, 493.
  " sources of, 492.
Citrate of magnesia, see Magnesia.
Claret dye, 779.
Clay, alum from, 171.
Coal, 931.
  " analysis of brown, 940.
  " anthracite, 938.
  " bituminous, 940.
  " Boghead, 945.
  " caking, 938.
  " cannel or parrot, 938.
  " chemical characteristics of, 934.
  " chemical composition of, 939.
  " cherry or soft, 938
  " comparative cost of, 1000.
  " composition of samples of, 942.
  " constituents of, 941.
  " consumption, 936.
  " different kinds of, 937.
  " distillation of, 998.
  " dust in mines, inflammable nature of, 950.
  " gas, 991.
  " gas as a source of heat, 1030.
  " gas manufacture, general description of, 1001.
  " Lignite, 937.
  " microscopic characters, 934.
  " mineralogical characters, 933.
  " mines, ventilation of, 952.
  " occlusion of gas in, 946.
  " origin of, 934.
  " splint or hard, 938.
  " tar, constituents of, 497, 506.
  " varieties of, 938.
COAL TAR DISTILLATION—497–520.
Coal tar distillation, average products from, 500.
  " condensers, 501.
  " fractionation of, 502.
  " mode of working, 500.
  " stills, 499.
  " treatment by the wet process, 504.
  " Fenner and Versmann's still, 505.
Coal washing, 967.
Coals used in gas manufacture, 994.
COBALT—520–531.
Cobalt, alloys, 521.
  " bloom, 521.
  " bronze, 531.
  " commercial oxide of, 522.
  " detection of, 523.
  estimation of, 524.
  " history of, 520.
  " manufacture of, 522.
  " metallurgy of, 521.
  " oxide of, commercial, 522.
  " oxides, 521.
  " principal compounds of, 523.
  " properties of, 521.
  " pyrites, 521.
  " separation of, 524.
  " silicate of, 531.
  " sources of, 520.
  " ultramarine, 530.
Cobaltine, 520.
  " analysis of, 520.
Cobaltous salts, 523.
Coccinine, 537.
Coccocerine, 538.
Cocculus indicus in beer, 337.
Cochenille ammoniacale, 540.
COCHINEAL—531–540.
Cochineal, carminic acid, 535.
  " cultivation of, 533.
  " dyes, 631, 753.
  " extraction of colouring matter, 534.
  " imported into London, 533.
  " insect, 531.
  " plantations, 532
  " red, distinction from other reds, 538.
  " scarlet, 540.
  " spectroscopic character of the colouring matter, 538.
  " valuation of, 538.
  " wax, 538.
Cœruleum, 530.
Coke, 914, 953.
  " desulphurization of, 967.
  " ovens, 956.
  " oven, Appolt's, 962
  " oven, Breckon and Dixon's, 965.
  " oven, Coppée's, 964.
  " oven, Pernolet's, 958.
Coking in open heaps, 954.
Colliery explosions, 947.
Colours, adjective, 629.
  " Croissant and Bretonnière's patent, 632, 767.
Combustion, 891.
Comparative cost of grain and carrots in the manufacture of alcohol, 124.
Concrete, 466.
  " asphalt, 359
  " Coignet's, 466.
  " for repairing steps of stairs, &c., 456.
Condy's process in the purification of acetic acid, 31.
Cooling alcohol, 72.
Copaiba balsam, 266.
Coppée's coke oven, 964.
COPPER—541–572.
COPPER ALLOYS—572–601.
Copper, acetates of, 42.
  " aceto-arsenite of, 260.
  " and lead in alcohol, detection of, 153.
  " and tin, alloys of, 582.
  " arsenite, 634.
  " assaying, dry way, 570.
  " assaying, wet way, 571.
  " black, 542.
  " Brankart's process, 554.
  " calcination of coarse metal, 550.
  " calcination, 545.
  " calciners for burnt pyrites, 563.
  " carbonate of, 599.
  " chemical character of, 541.
  " chemical reactions of first process, 547.
  " classification of the ores, 544.
  " close furnaces, 565.
  " coloration test, 598.
  " combined furnaces, 565.
  " estimation of, 597.
  " first melting, 549.
  " furnaces, German, 559.
  " fusion of calcined coarse metal, 551.
  " glance, 543.
  " grey, 543.
  " historical account of, 541.
  " lixiviation, 567.
  " mechanical furnaces, 563.
  " mechanical preparation of ores, 544.
  " melting of the calcined ore, 548.
  " mica, 544.
  " minerals, list of, 542.
  " Napier's process, 555.
  " native, 542.
  " old Mansfield process, 561.
  " open reverberatory furnaces, 566.
  " ores, 542.
  " oxide of, 598.
  " phosphides, 592.
  " physical character of, 541.
  " precipitation, 568.
  " preparation of the pure metal, 541.
  " preparation of, 545.
  " purple, 543.
  " pyrites, 543.
  " red, 542.
  " reverberatory furnaces, 563.
  " Rivot and Phillip's process, 554.
  " roasting the blue or white metal, 552.
  " rotating calciner, 564.
  " salts, 598, 734.
  " smelting, application of wet process to burnt pyrites, 562.
  " smelting at Swansea, 544.
  " smelting in France, 556
  " smelting in Germany, 558.
  " smelting, foreign modes of, 556.
  " smelting, Tharsis Company's calciner, 565.
  " Spence's calciner, 547.
  " sulphate of, 600.
  " the lime process, 570.
  " Trueman and Cameron's process, 555.
  " wet process, 561.
Copperas, 734.
Cordial gin, recipe for, 108.
Coriander seeds, 109.
Corn, analysis of Indian, 411.
  " analysis of the ash of Indian, 411.
  " cleaning and winnowing, 411.
  " Indian, 410.
  " preparation of, 411.
Cotton, kinds of, 365.
  " and wool, mixed, to detect, 756.
  " cloth for dyeing, preparing, 759.
  " in linen, to detect, 756.
  " in silk, to detect, 757.
  " wax, 621.
Cream of tartar, 738.
Cresol, 613.
Cresylic phenol, 613.
Crimson dyes, 761, 763, 774, 775.
Croissant and Bretonnière's new colours, 632, 767.
Cryolite, 180.
  " alum from, 173.
Cumene, 344.
  " pseudo, 344.
Cumidine, 208.
Cupric sulphate, 600.
Cuprite, 542.
Cyanosite, 543.

D

Daniell's pyrometer, 872.
Dead, disposal of the, 602.
Decomposition of alcohol, 64.
Decorator's cement, 467.
Depositing metals, electric power suitable for, 800.
Diacetate, 47.
  " insoluble, with five equivalents of water, 39.
  " insoluble, with two equivalents of water, 40.
  " soluble, with four equivalents of water, 39.
Diamidobenzene, 208.
Diamido toluene, 208.
Dibasic cupric acetate, 43.
Dicas' hydrometer, 149.
Dilatometer, Silbermann's, 148.
Dilution of alcohol, Gay-Lussac's tables for, 150–152.
Dimethyl aniline, 210.
  " aniline, manufacture of, 216.
Dioptase, 543.
Diphenylamine, manufacture of, 215.
Dips, manufacture of candle, 444.
DISINFECTANTS—601–619.
Disinfectants, artificial, 612.
  " carbolic acid, 612.
  " comparative values of, 614.
  " Cottrell's dust filter, 611.
  " disposal of the dead, 602.
  " Dr. Tyndall's experiments, 604.
  " liquid and solid, 601.
  " natural, 611.
  " sulphurous acid, 617.
  " volatile, 601.
Disinfecting agencies, 601.
  " stoves, figures of, 619.
Distillation, 76.
  " Indian method of, 123.
  " of gas coal, 998.
  " of sawdust for pyroligneous acid, 24.
  " of wood, steam, 16, 33.
Distillery, whisky, 100.
Divi divi dyes, 633.
Drab dyes, 767, 771, 777, 778.
Drying cotton, 377.
Dunder, use of, in rum manufacture, 114.
Dust filter, 610.
Dutch madder, 749.
DYEING AND CALICO PRINTING—620–792.
Dyeing, adjective colours, 622.
  " alkali process, 630.
  " and printing, chemistry of, 620.
  " black, linen, 768.
  " colours fixed by oxidation, 640, 646.
  " cotton, 644, 723.
  " cotton, colours not requiring a mordant, 644.
  " cotton vat, 730.
  " cotton yarn, 757.
  " double muriate, 739.
  " finishing, 781.
  " German vat, 729.
  " greenish mode grey linen, 768.
  " indigo, 622.
  " indigo blue, 622.
  " indigotin, 622.
  " linen, 726.
  " linen and jute, 767.
  " management of the vats, 769
  " mineral and pigment colours, 622.
  " mixed goods, 726.
  " natural substantive colours, 622.
  " on mordants, 636, 644.
  " pastel vat, 728.

Dyeing, potash vat, 728.
“ practical operations, 751.
“ processes, 722.
“ receipts, cotton, 760.
“ receipts, mixed fabrics, two colours, 779.
“ receipts, mixed fabrics, one colour, 779.
“ receipts, mixed garments, 780.
“ receipts, new colours on cotton, 764.
“ receipts, silk, ungumming, 773.
“ receipts, to prepare colours, 751.
“ wool ponceau, 776.
“ Turkey red, 645, 782.
“ “ French process, 784.
“ “ Fries' process, 785.
“ “ nitric acid process, 788.
“ “ oiled rose grounds, 792.
“ “ process, 783.
“ “ Swiss process. 786.
“ “ with artificial alizarin, 767.
“ silk. 647, 725, 768.
“ substantive colours, 622.
“ vats, 727.
“ woad vat, 728.
“ wool. 647, 726.
“ woollen stuffs. 723.
“ woollen stuffs, preparation, 723.
Dyestuffs for wool and silk 648–652.
Dynamic theory of heat, 886.
Dynamite, 854.
“ see Nitro-glycerine.

E

Ebullition of water, 883.
Electric etching, 829.
“ power, management of, 809.
“ power suitable for depositing metals, 800.
Electro-coating metals, applications of, 825.
“ deposition of copper on iron and zinc, 826.
“ deposition of iron on copper plates, 828.
“ deposition, reduction of ores, 829.
“ depositing solutions, aluminium, 799, 824.
“ depositing solutions, antimony, 799, 824.
“ depositing solutions, bismuth, 799, 824.
“ depositing solutions, brass, 797, 820
“ “ bronze, 798, 822.
“ “ cadmium, 799, 823.
“ “ chromium, 800, 825.
“ “ cobalt, 799, 824.
“ “ copper. 795, 816.
“ “ German silver, 798, 822.
“ “ gold, 797, 819.
“ “ iron, 798 822.
“ “ lead, 799, 824.
“ “ methods of working, 815.
“ “ molybdenum, 800, 825.
“ “ nickel, 798, 822.
“ “ palladium, 799, 823.
“ “ platinum, 798, 823.
“ “ silicium, 799, 824.
“ “ silver, 796, 818.
“ “ thallium, 800, 825.
“ “ tin, 798, 823.
“ “ titanium, 800, 825.
“ “ tungsten, 799, 825.
“ “ zinc, 799, 823.
ELECTRO-METALLURGY—792-831.
Electro-metallurgy, copper-zinc battery. 801.
Electro metallurgy, copper-zinc double fluid battery, 802, 803.
“ Daniell's battery, 802.
“ iron-zinc battery, 801.
“ method of working, 793.
“ platinized-silver zinc battery, 801.
“ platinum-zinc double fluid battery, 803.
“ single cell apparatus,
“ 802.
“ Smee's battery, 801.
“ Sturgeon's battery, 802.
“ theory of, 830.
“ Wollaston's battery, 801.
Electro-nickeling, 828.
“ plating, 825.
“ plating, cleaning the articles, 825.
Electrotypy, applications of, 828.
Electrotypy, copying coins, 828.
Emeraldine, 239.
ENAMELS—831-837.
Enamels, black, 836.
“ blue, 836.
“ coloured, 834.
“ dead white. 833.
“ furnaces. 832.
“ green, 835.
“ painting on, 834.
“ purple, 834.
“ red. 835.
“ transparent and opaque, 832.
“ violet, 836.
“ yellow, 835.
Enamelling on iron. 836.
Energy, science of, 887.
Eosin dye. 628.
Epsom salts, 170.
Erythrite, 521.
Erythrobenzol, 223.
ETHER—837-850.
Ether, acetic. 57.
“ adulteration of, 844.
“ benzoic, 847.
“ butyric, 847.
“ composition of, 843.
“ flavours. 850.
“ formic, 847.
“ hydrochloric, 845.
“ known to the alchemists, 837.
“ manufacture of, 838.
“ methyl, 845.
“ methylated, 842.
“ nitric, 849.
“ nitrous. 849.
“ œnanthic or pelargonic, 848.
“ preparation of, 837.
“ properties of, 843.
“ rectification of, 840.
“ theory of its formation, 842.
“ uses of, 844.
“ valerianic, 848.
Ethyl alcohol, 60.
“ aniline, 211.
“ benzoate of, 847.
“ butyrate of, 847.
“ chloride of, 845.
“ iodide of, 845.
“ formate of, 847.
“ mauveine, 237.
“ nitrate, 848
“ pelargonate, 111.
“ valerate, 848.
Ethylic oxide, 837.
Evaporation, 883.
Excise regulations, 67.
Experiments in mashing, Dr. Graham's, 296.
Explosion by detonation, 853.
“ colliery. 947.
EXPLOSIVES, 850–858.

F

Feather alum, 159.
Felspar, alum from, 172.
Fermentation, 72, 73.
“ acetous, 4.
Fermented alcoholic liquors, 4.
Fermenting square, 318.
“ tuns, 75, 317.
Ferric acetates, 46.
“ oxides, 633.
Ferrous acetate, 45.
Filtration of air for respiration, 607.
Filter for dust, 610.
“ Cottrell's dust, 611.
Fireman's respirator, 608.
Flavours from ether, 850.
Flax dyeing, 382.
“ cold water retting, 383.
“ dew retting, 383.
Flour mill, 414.
“ section of, 416.
Flour of arsenic, manufacture of, 253.
Flower of madder, 630.
Fluorescein, 628.
Fly poison, manufacture of, 259.
Fibres, to detect animal and vegetable in cloth, 756.
Fire-damp, composition of, 947.
“ properties of, 948.
FOOD, PRESERVATION OF ANIMAL—858-869.
Food, preservation of, by antiseptics, 866.
“ “ by heat, 868.
“ “ drying process, 863.
“ “ patents, 859.
“ “ use of cold, 864.
Folding cotton, 379.
Formate of ethyl, 847.
Formic ether, 847.
French berries, 632.
Fruit vinegar, 15.
Fuchsine dyes, 217, 626.
“ manufacture of, 222.
“ residues, utilization of, 228.
“ retorts for the manufacture of, 225.
FUEL—869–982.
Fuel, analysis of, 905.
“ Appolt's coke oven, 962.
“ artificial, 969.
“ Breckon and Dixon's coke oven, 965.
“ charcoal and coke, 914.
“ coal, 933.
“ coke. 953.
“ coke ovens, 956.
“ calorific power of, 894.
“ compression of peat, 928.
“ Coppée's coke ovens, 964.
“ gaseous, 971.
“ heating power of various, 900.
“ its calorific intensity, 898.
“ modes of using, 902.
“ peat, 925.
“ Pernolet's coke ovens, 958.
“ Siemens' furnace linings, 981.
“ Siemens' gas furnace, 972.
“ Siemens' gas producer, 973.
“ Siemens' rotatory iron furnace, 978.
“ Siemens' steel melting furnace, 980.
“ waste of, loss of heat, 893.
“ wood, 909.
Furnaces for smelting antimony, 244.
Fusel oil, how recognized, 106.
“ treatment of, in whisky, 4.
Fustet dyes, 632.
Fustic dyes, 632, 653.

G

Galvanic batteries, 800.
“ deposition, direction of current, 809.
“ “ connection with depositing trough, 809.
“ “ connections, 812.
“ “ influence of heat, 813.
“ “ insulation of, 809.
“ “ management of liquids, 811.
“ “ quantity of electric force, 810.
“ “ size of battery plates, 810.
“ “ treatment of plates, 811.
Galvanometers, 813.
Gambier dyes, 633.
Garancin dyes, 630.
GAS—982–1024.
Gas, air, 1020.
“ ammonia, 986.
“ average composition of London, 994.
“ burners, 1021.
“ charging and drawing retorts, 1003.
“ chief constituents of coal, 994
“ coal, 991.
“ coal, new methods of purification, 1001.
“ coal, governor, 1011.
“ comparative results from various coals, 997.
“ condenser, 1004.
“ consumers' governors, 1027.
“ “ fittings, 1028.
“ “ meters, 1028.
“ estimation of specific gravity, 1030.
“ exhausters. 1005.
“ furnace, Siemens' regenerative. 972.
“ historical account of illuminating, 992.
“ holders. 1010.
“ illuminating power of, 1032.
“ Letheby's photometer, 1033.
“ liquor, ammonia from, 184.
“ liquor, preparation of ammonia from, 193.
“ manufacture, description of coals used in, 994.
“ marsh, 989.
“ muriatic or hydrochloric acid, 989.
“ nature of illuminating, 993.
“ new methods of production, 1019.
“ olefiant, 990.
“ photometers, 1032.
“ produced in wood distillation, 24.
“ productions from various coals, 995
“ purifiers, 1007.
“ purification of, 1011.
“ residual products, 1024.
“ retorts, 1001.
“ scrubber and washer, 1006.
“ singeing, 664.
“ station meter, 1009.
“ Sugg's illuminating power meter, 1036.
“ supply, parliamentary regulations, 1031.

Gas, testing, 1032.
  " testing for impurities, 1037.
  " the referees' sulphur test, 1037.
Gaseous matter, theory of, 983.
Gases, absorption by liquids and solids, 984.
  " diffusion of, 984.
  " discovery of, 982.
  " expansion of, 877.
  " liquefaction and solidification of, 985.
  " measurement of, 985.
  " preparation and properties of, 986.
  " specific gravity of, 986.
  " transpiration of, 986.
Gay-Lussac's alcoholometric tables, 131–139.
  " tables for dilution of alcohol, 150, 152.
Geneva spirits, 107.
German barm, 420.
  " silver, 581.
Geranosine, 231.
Gin, British, 107.
  " cordial, recipe for, 108.
  " fine, recipe for, 108.
  " Geneva, recipe for, 108.
  " Hollands, 107.
  " London, recipe for, 108.
  " plain Geneva, recipe for, 108.
  " west country, recipe for, 108.
Glacial acetic acid, 1.
  " apparatus for preparation of, 2.
Glue, marine, 456.
  " patent, 392.
Gold and straw dyes, 771, 773.
Grain, grinding, 412.
  " millstones for, 413.
  " sifting, 412.
Grains of paradise, 109.
Green carbonate of copper, 542.
  " dyes, 221, 239, 240, 260, 531, 626, 632, 634, 653, 761, 764, 767, 771, 773, 777, 778, 779.
  " verdigris, 43.
Grey dyes, 222, 241, 242, 764, 773, 775.
Gros bleu, 772.
Gris d'aniline, 773.
Guano, salts of ammonia from, 198.
Gun cotton, 851.
  " compressed, 855.
  " discovery of, 851.
  " manufacture of, 852.
  " wet, 857.
Gun metal, 586.
  " furnaces for, 587.
  " proportions used for cannons, 586.
Guns, Uchatius' mode of making, 590.
Gypsum, 467.

H

Ham's process of vinegar making, 14.
Harmaline, 219.
Hartshorn, salt of, 198.
Heat, conduction and convection of, 878.
  " developed during combustion in oxygen, 896.
  " dynamic theory of, 886.
  " expansive action of, 870.
  " latent, 882.
  " mechanical equivalent of, 888.
  " radiation of, 879.
  " sources of, 869.
  " specific, 880.
Hemp, 621.
Hops, 284.
Hop cones, constituents of the ash of, 286.
Hops, lupulin in, 285.
  " medicinal qualities of, 286.
  " oil of, 285.
  " preparation of, 286.
  " selection of, for beer, 286.
  " tables showing the quantity of, per quarter of malt, 308–310.
Hydraulic cement, 460.
  " limestones, 462.
Hydrate of methyl, 54.
Hydrated lime, 459.
Hydric chlorate, 475.
  " chlorite, 475.
  " hypochlorate, 475.
  " perchlorate, 475.
Hydrochloric acid in vinegar, 37.
  " ether, 845.
Hydrogen, 988.
  " calorific power of, 897.
  " sulphuretted, 991.
Hydrometer, Sikes', 140.
Hypochlorous acid, 475.

I

Ice, use of, in brewing in Bavaria, 332.
Improvements in alum manufacture, 174.
Indian corn, 410.
  " method of distillation, 123.
Indigo calico printing, 641.
  " dyes, 653, 745.
Indigo-purpuric acid, 623.
Indigo-sulphuric acid, 623, 653.
Infection, causes of, 603.
Ink marks, indelible, from cloth, 756.
Inks, sympathetic, 523.
Iodide of ethyl, 845.
  " of methyl, 846.
Iron acetates, 45.
  " and copper alloys, 573.
  " liquor, 753.
  " salts, 734.
  " stains in cloth, to remove, 756.
Ivory black, 395.

J

Japanese wax, 452.
Juniper berries, 109.

K

Kermes, 631.
  " mineral, 247.
Kino, 633.

L

Lac-dye, 631.
Lacquering brass, 580.
Lagoons of Tuscany, 398.
Lambick beer, 333.
Lamp, safety, 949.
Latent heat, 882.
Lavender dye, 762, 770.
Lead acetates, 47.
  " arsenates of, 264.
  " brown acetate of, 47.
  " chromates, 634.
  " colour, 776.
  " dibasic acetate, 49.
  " sesquibasic acetate, 49.
  " sexbasic acetate, 49.
  " tribasic acetate, 49.
  " white acetate of 48.
Leghorn colour, 761.
Lemon juice, citric acid from, 494.
  " peel, 109.
Levinstein's Dorothea, 239.
Liebethanite, 543.
Ligneous matter, products of the combustion of, 914.
Lilac, 653, 638.
Lima wood, 631.
Lime, 457.
  " acetate of, 49.
  " acetate of, Völckel's process for obtaining, 29.
  " hydrated, 459.
  " hydraulic, 460.
  " hydraulic, quality of, 461.
  " kilns, 457.
  " water, 753.
Limestones, hydraulic, 462.
Linen, 621.
  " bleaching, 385.
  " bleaching, Irish method, 385.
  " bleaching, old Bielefield method, 385.
  " bleaching, Bouchard's continuous process, 386.
Liquidambar, 268.
Liquid ammonia, 182.
Liquids, expansion of, 877.
Liquor ammonia, 182.
Liquorice, 109.
Litmus, 624.
Logwood, 631, 748.

M

Macarat, dark, 764.
Maclurin, 632.
Madder, 629, 748.
  " Alsatian, 749.
  " extracts, 630.
  " Indian, 631.
  " of Avignon, 749.
  " spirit, 124.
Magdala red, 627.
Magenta dyes, 624, 768.
Magnesia, arsenate of, 264.
  " in cement, 463.
Magnesium sulphate, 170.
Magneto-electric machines, 803.
  " Gramme's, 806.
  " management of, 814.
  " Siemens' armature, 805
  " Wilde's, 804.
Maize whiskey converted into vinegar by ozone, 5.
Malachite, 542.
Malt, air-dried, 279.
  " amount of proof spirit from, 77.
  " chemical examination of, 280.
  " crusher, description of, 283.
  " extract, specific gravity and strength of, 335.
  " grinding, 287.
  " vinegar, fielding process, 9.
  " vinegar for household use, 10.
  " vinegar, manufacture of, 7.
Maltase, 297.
Malted barley, composition of raw and, 281.
Malting, 7.
  " botanical change in, 275.
  " excise regulations, 274.
  " in Bavaria and Bohemia, 276.
  " in Munich, 281.
Malvaceæ, 749.
Manganese, 491, 737.
  " acetate, 51.
  " ores, composition of, 491.
Manganic oxide, 633.
Mangling cotton, 377.
Marine glue, 456.
Maroon dye, 777.
Marsh gas, 989.
Mash-tun for beer, 291.
Mashing, 8, 69.
  " in beer, 289.
  " Levesque's table for time and temperature, 295.
  " machinery, 294.
  " temperature in, 290.
Maurexide, 6_9.
Mauvaniline, manufacture of, 228.
Mauve, 653.
  " manufacture of, 236.
Mauveine, 219.
Meat extract, Liebig's, 863.
Mecca balsam, 267.
Melaconite, 542.
Mesitylene, 344.
Metallic acetates, 54.
Metallurgy, 352.
Metatoluidine, 207.
Meta-xylene, 343.
Methyl, acetate of, 58.
  " aniline, 210.
  " aniline, manufacture of, 216.
  " chloride, 845.
  " diphenylamine, 210.
  " green, 241.
  " hydrate of, 54.
  " iodide of, 846.
Methylated spirit, 56.
Methylic acetate, 58.
  " alcohol, 54.
Metallic salts in vinegar, 38
Mildew from cotton, to remove, 756.
Millstones, dressing, 413.
Mineral and pigment colours, 633.
  " dyes and mordants, 731.
  " pitch, 357.
Mispickel, 521.
Modes on alpaca, dyeing, 777.
Mordants, 634.
Molasses, distillation of, 118.
Morin, 632.
Mortar, 459.
  " hydraulic, 460, 468.
  " ordinary, 468.
Moritannic acid, 632.
Mosaics, 468.
Mother of vinegar, 4.
Mulberry dyes, 777.
Munjeet dyes, 631.
Muntz's metal, 580.
Mutton suet for making candles, 432.
Myrobalans, 633.
Myrospermum pubescens, 270.

N

Naphtha, 356.
  " wood, 54.
Naphthalene red, 627.
Nessler's solution, estimation of ammonia by, 203.
Neutral acetate, 47.
Nickel silver, 581.
Nitrate of iron, 753.
  " of tin, 754.
Nitric acid in vinegar, 38.

Nitric ether, 849.
  " oxide, 989.
Nitrite of ethyl, 848, 849.
Nitro-benzene. 348.
Nitro-benzol, 348.
  " apparatus for preparing, 350.
  " manufacture of, 349.
Nitro-cellulose, 858.
Nitro-coccusic acid, 536.
Nitrocumene, 348.
Nitro-glycerine, manufacture of, 855.
Nitro-toluol, Coupier's, 224.
Nitrogen, 990.
Nitrous oxide, 989.
Nut-galls, 633.

O

Oats, 410.
  " analyses of, 410.
  " analyses of the ash of, 410.
Ocuba wax, 452.
Oenanthic ether, 848.
Oil stains in cloth, to remove, 756.
Olefiant gas, 990.
Oleo-resins, 266.
Olive dyes, 764, 772, 777.
Oliverite, 544.
Opobalsam, 267.
Orange dyes, 222, 754, 761, 768, 771, 776, 778.
  " peel, 109.
Orchil, 761.
Organic colouring matters, 741.
Orpiment, 634.
  " manufacture of, 260.
Orris root, 109.
Orseille, 624.
Orthotoluidine, 208.
Ortho-xylene, 343.
Ovens for sawdust distillation. 25.
  " used for wood distillation, 23.
Oxalate of tin, 754.
Oxide of aluminium, 178.
  " of boron, 406.
  " of cobalt, commercial, 522.
  " of copper, 598.
  " silicic, 463.
Oxides, 633.
Oxychloride of bismuth, 354.
Oxygen, 990.
Ozone, maize whiskey converted into vinegar by, 5.

P

Pale ale, 327.
Palm wax, 452.
Palmitic acid, 441.
Pansy dyes, 778.
Paracopaiba balsam, 267.
Paraffin, 451.
  " agents employed in purifying, 451.
  " annual production in Scotland, 451.
  " candles, 451.
  " manufacture of, 451
  " purification and bleaching, 451.
  " value of, for candle making, 452.
Paraniline, 208.
Paratoluidine, 206.
Parian cement, 467.
Para-xylene, 343.
Pasteur's process for making vinegar, 11.
  " researches on yeast. 314.
Pauer's process for preparation of acetic acid and acetates, 26.
Peach wood, 631.
Peat, 925.
  " ammonia from, 199.
  " charcoal, 930.
  " compressed, 931.
  " compression of, 928.
  " distillation of, 929.
  " preparation of, 927.
Pelargonate of ethyl, 848.
Pentasulphide of antimony, 248.
Peonin, 628.
Perchloric acid, 475.
Permanganate of potash as a disinfectant, 617.
Pernolet's coke oven, 958.
Persian berries, 632.
Peru balsam, 269.
Phenol colours, 627.
Phenyl rosaniline, 627.
Phosphine, 627.
Phosphor bronze, 593.
  " bronze for guns, 596.
  " " qualities of, 595.
  " " testing, 595.
Photometry, 1032.
Picric acid, 627, 653.
Picric acid in beer, 336.
Pincoffin, 630.
Pink dyes, 638, 653, 767, 770, 776, 778.
Poison-tower, arsenic, 257.
Ponceau, 773.
Porter, 328.
  " grists, table of, 329.
  " gyle, 329.
  " worts, 329.
Portland cement. 466.
  " " analyses of various samples, 466.
Potassium acetates, 53.
  " chloride for precipitating alum, 166.
  " diacetate, 53.
Potato spirit, 120.
Potteen whiskey, 103.
Precautions in arsenic manufacture, 258.
Price's patent candles, 439.
Printing of wool, 652
Production of different woods on distillation, 22.
Properties of alcohol, 62.
  " of aluminium, 180.
Pseudo-purpurin. 629.
Puce dyes, 754, 762, 764, 777.
Pumping water for brewing, 287.
Purification of pyroligneous acid. 27.
Purple dyes, 239, 624, 626, 628, 639, 640, 653, 755, 762, 773.
Purpurin, 629.
Purree dyes, 632.
Pyroacetic spirit, 58.
Pyroligneous acid, 16.
  " acid from sawdust, 24.
  " acid, purification of, 27.
Pyrolusite, 521.
Pyrometer, Daniell's, 872.
  " Siemens' electrical, 873.
Pyroxylic spirit, or wood naphtha, 54.

Q

Quercitron, 631.

R

Randall's description of pyroligneous acid manufacture, 26.
Raspberry brandy, 112.
Realgar, manufacture of, 259.
Receipts for dyeing cotton, 760.
Rectification of spirit, 105.
Red cotton spirit, 755.
  " dyes, 217, 218, 231, 536. 626, 628, 638, 652, 653, 760, 768, 775.
  " liquor, 753.
  " liquor, sesquiacetate of alumina, 40.
  " liquor receipts, 40.
  " ruthite, 543.
  " sanders' wood, 631.
Refrigerators for beer, various, 313.
Respiration, filtration of air for, 607.
Respirator, firemen's, 608.
  " smoke, 610.
Retting flax, 383.
Rice, 411.
  " analyses of, 411.
Rodonda phosphate, alum from, 174.
Roman alum, 156.
  " cement, 461, 464.
  " " composition of 465.
  " " manufacture of, 465.
  " " kilns used, 465.
  " vitriol, 600.
Rosaniline, 626.
  " mother liquors, 230.
  " salts, preparation of, 227.
  " testing, 682.
Rose dyes, 467, 775.
Roseine, 626.
Rosatoluidine, manufacture of, 230.
Rosolic acid, 218.
Rouge de toluene, 218.
Ruby, maroon, &c., dyes, 770.
Ruficarmine, 538.
Ruficoccine, 537.
Rum, 113.
  " from beetroot, 118.
  " manufacture, use of dunder in 114.
  " stills, 115.
  " stills, Laugier's, 119.
  " West India, 117.
Rusma, 260.
Rye, 409.
  " analyses of. 409.
  " analyses of ashes, 409.

S

Saccharometer, 300.
Saccharometer in beer, 299.
Safety lamp, 949.
Safflower dyes, 624, 750.
Saffranine dyes, 218, 231 452, 627.
  " ponceau, 767.
Sal-ammoniac, 188.
Sal-volatile, 199.
Salicylic acid, 613.
Salmon dyes, 771.
Salt of hartshorn, 199.
  " Saturn, 47.
Salts, dyers', 634.
  " ammoniacal, 183.
  " preparation of rosaniline, 227.
  " of ammonia from guano, 198.
Sanders, fast, 7 8.
Sang de Bœuf, 774.
Santal wood, 631.
Sawdust, distillation of, for pyroligneous acid, 24.
Sawdust distillation, ovens for. 25.
Scarlet dye, 218, 231 773, 775, 776.
  " finishing spirit, 754.
Scotch ales, 328.
Scouring cottons, 367, 376, 377.
  " cotton with caustic alkali, 374.
Sea-weed, acetic acid from, 15.
Sesquibasic cupric acetate, 43.
Sesquicarbonate of ammonia, 199.
Sesquichloride of tin, 739.
Siemens' electrical pyrometer, 873.
  " regenerative gas furnace, 972.
  " rotatory iron furnace, 978.
  " steel melting furnace, 980.
Sikes' hydrometer, 140.
Silber burner, 1026.
Silica, 463.
Silicate of bronze, 531.
Silicic oxide, 463.
Silk, 621.
  " bleaching, 390.
  " Claussen's process, 391.
  " dyeing, 647, 768.
  " dyeing, preparation for, 647.
Silver, nickel, 581.
  " residues of copper, 569.
Singeing cotton, 366.
Skutterudite, 521.
Slate dyes, 771, 778
Smalt, 524.
  " analysis of, 528.
  " furnaces, 527.
  " fusion, 525.
  " grinding and washing, 528.
  " history of manufacture, 529.
  " roasting, 525.
  " testing, 530.
  " treatment of ore, 524.
  " uses of, 529.
Smaltine, 528.
Smelting antimony, 243.
Smoke cap, Captain Shaw's, 609.
  " respirator, Cottrell's face piece, 610.
Soda, acetate of. 51.
  " biborate of, 400.
  " use of, as a food preservative, 52.
Sodium acetate, 51.
  " aluminate, 173.
Solferino dye, 626.
Solids, expansion of, 8 1.
Solomons and Azulay's sawdust process, 26.
Solutions for electro-depositing metals, 795.
Souring cotton, 374, 376, 377.
Sparging, 298.
Specific gravity of alcohol, 62.
  " gravity tables, Ure's, 143.
Spence's process of alum manufacture, 171.
Spermaceti candles, 454.
  " purification of, 455.
Spirit black, 610.
  " extract, 630.
  " from the berries of Sorbus aucuparia, 125.
  " from the toddy palm, 122.
  " from rice, 122.
  " printing, calico, 640.
  " rectification of, 105.
  " specific gravity and strength of, 335.
  " table for the real strength of, 131.
Stannous acetate, 53.
Starching cloth, 378.
  " machine, 378.
Stamping and ending cotton, 366, 379.
Steam distillation of wood, 33.
  " elastic force of, 885.
  " retting of flax, 383.
Stearic acid, 435.
  " bleaching, for candles, 450.
  " by sulphuric acid process, 439.
Stearin, 435.

Stearine candles, 448.
Steeping cotton, 376.
Stein's tables for detecting different organic colours on tissues, 654, 656.
Stibnite, or grey antimony ore, 243.
Still, alcohol, Adam's, 82.
" Alègre's, 96.
" aniline, 213.
" Canadian, 104.
" Coffey's 81.
" Derosne's, 86.
" Dorn's, 91.
" Laugier's rum, 119.
" Miller's, 99.
" Perrier's, 80.
" Pistorius', 92.
" Pontifex's rum, 116.
" principally employed on the continent, 110.
" rum, 115.
" Schwartz's, 94.
" Scotch, 79.
" Siemens', 95.
" Solimani's, 84.
" St. Marc's, 89.
Stone colour dyes, 762.
Storax balsam, 267.
" opaque liquid, 268.
" pellucid liquid, 268.
Straw colour dye, 761.
Stucco, 467.
Substances which arrest acetification, 12.
Sugar and cider vinegar receipts, 11.
" in beer, tables showing quantity of, 299.
" of lead, 47.
Sulphantimonites, 249.
Sulphate of alumina, 177.
" of ammonia, 196.
" of indigo, 752.
Sulphide of antimony, 244.
Sulphides, 634
Sulphuretted hydrogen, 991.
Sulphuric acid in vinegar, 36.
" ether, 837.
Sulphurous acid, 991.
" as a disinfectant, 617.
Sumach, 633.
Sympathetic inks, 523.

T

Tallow melting, 433.
" melting by steam, vats for, 434.
Tannic acids, 632.
Tannin, 633.
Tar, constituents of, 506.
" lake of Trinidad, 359.
Tartar, 738.
Tartaric acid in vinegar, 38.
Temperature in mashing, 290.
Tenorite, 542.
Tetrahedrite, 543.
Tharsis Company's calciner, 565.
Thermodynamics first law, 888.
" second law, 890.
Thermo-electric batteries, 807.
" " Clamond's thermopile, 808.
" " management of, 815.
Thermometer, 870.
Thickening for reds, 638.
Tin, 739.
" acetate of the protoxide of, 53.
" double muriate of, 754.
" oxalate of, 754.
" salt, 739.
" single muriate of, 753.
Tincal, 401.
Tolu balsam, 768.
Toluene, 343.
Toluidine, 206.
Torbanehill mineral, 945.
Tralles' alcoholometric tables, 126-131.
Tribasic cupric acetate, 43.
Trichloride of antimony, 249.
Trinitrophenol, 627.
Trioxide of antimony, 249.
Trisulphide of antimony, 247.
Turkey-red dyeing, 645, 652.
Turmeric, 632, 653, 751.
Tuscany, lagoons of, 398.
Tyndall, Dr., on dust and germ laden air, 603.

U

Unfermented bread, 425.
Ultramarine, 634.
Ultramarine, cobalt, 530.
Uses of ammonia, 182.

V

Val-de-Travers asphalt, 362.
Valerate of amyl, 848.
Valerianic ether, 848.
Vats for tallow melting by steam, 434.
Ventilation of coal mines, 952.
Verdet, 42.
Verdigris, 42.
" adulteration of, 44.
" blue, 43.
" green, 43.
Verditer, 599.
Violaniline, manufacture of, 228.
Violet de Lyons, manufacture of, 237.
Violet dyes, 219, 220, 237, 238, 241, 270, 653, 771, 777, 778, 779.
Violets, methyl, manufacture of, 239.
Violets, thickenings for, 638.
Vinegar, aromatic, 34.
" for pickling, 10.
" from beet-root, 15.
" from maize whiskey, 5.
" from sour ale, 15.
" from sugar and cider, 11.
" fruit, 15.
" hydrochloric acid in, 37.
" malt, for household use, 10.
" malt, manufacture of, 7.
" metallic salts in, 38.
" mother of, 4.
" nitric acid in, 38.
" Pasteur's process for making, 11.
" plant, 4.
" pure acetic acid from brandy, 34.
" quick process, 11.
" sulphuric acid in, 36.
" tartaric acid in, 38.
" testing, 35.
" manufacture of wine, 6.
" purification of wood, 27.
Vitriol, blue, 600.
" Roman, 600.
Volatile disinfectants, 601.
Völckel's process for obtaining acetate of lime, 29.

W

Washing cotton, 373, 377.
Water used in brewing by the Burton brewers, 284.
Wax, bees, 452.
" bleaching, 453.
" candles, 452.
Wax, cochineal, 538.
" Japanese, 452.
" palm, 452.
" tapers, 454.
Weld, 632, 751.
Wheat, analyses of, 408.
" composition of the ashes of, 408.
" inorganic constituents of several varieties of, 407.
" nutritive quality of various kinds of, 406.
Whiskey, 66.
" distillery, 100.
" maize, converted into vinegar by ozone, 5.
" potteen, 103.
White colours for dyeing, 771, 773.
Whitneyite, 544.
Wicks, machines for preparing, 443.
Widemann's experiments on diluted alcohols, 5.
Wine colour, 771.
" vinegar, manufacture of, 6.
Woad, 751.
Wood, action of heat on, 913.
" amount of moisture in, 909.
" as fuel, value of different kinds, 911.
" carbonizers, 20.
" constituents of, 912.
" density of, 910.
" distillation of, 16.
" distillation, products of, 16.
" distillation, size of ovens used, 23.
" distilled, kinds of, 21.
" extracts, 744.
" mineral constituents of, 913.
" naphtha, 54.
" productions from different kinds of, 22.
" spirit, 54.
" spirit, chloroform from, 474.
" spirit, purification of, 55.
" solid constituents of, 911.
" steam distillation of, 33.
" vinegar, purification of, 21.
Wool, 621.
" dyeing, 647.
" dyeing, preparation for, 647.
" printing of, 652.
Woollen cloth, bleaching, 388.
Wort, attenuation of the, 74.
" cooling the, 311.
" imbibed by hops, table of, 310.
" refrigerating, 312.
" strength of the, 72.
Woulfe's bottles, 78.

X

Xenylamine, 209.
Xylene, 343.
Xylidine, 208.
" red, 218, 231.

Y

Yeast, 314, 420.
" Pasteur's researches on, 314.
" pressing machinery, 325.
" purification and preservation of, 325.
" testing of, 315.
Yellow dyes, 222, 531, 628, 632, 639, 640, 653, 745, 754, 764, 768, 771, 773, 776.

Z

Zinc, 741.
" acetate, 54.

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